LIST OF BIBLIOGRAPHIES.

(To 31st December, 1941).

Price per copy : Non-Members 2/6.
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No. 1. "Fluidity and viscosity of metals." (Covering the period from 1902 to 1935).

No. 2. "Certain physical constants of iron and steel" (Specific heat, heat of transformation, thermal conductivity and expansion, electrical resistance and conductivity). (Covering the period 1930 to 1935).

No. 3. "Design, manufacture, properties and use of ingot moulds for steel ingots." (Covering the period 1899 to 1935).

No. 4. "The influence of arsenic and tin on the properties of iron and steel. Part I.—Arsenic." (Covering the period 1864 to 1936). "Part II.—Tin." (Covering the period 1901 to 1936).

No. 5. "The manufacture, properties and testing of steel castings. (Not including moulding sands)." (Covering the period from 1920 to 1937).

No. 6. "Gas producer practice." (Covering the period 1902 to 1936).

No. 7. "Flakes (hair-cracks, snowflakes), ghost lines, banded structure and fissures in steel." (Covering the period 1918 to 1937).

No. 8. "The physical chemistry of the open-hearth process." (Covering the period 1920 to 1937).

No. 8A. "The physical chemistry of the open-hearth process." (Covering the period 1938 to 1940). (Supplement to No. 8).

No. 9. "Grain-size in steel (including abnormality, normality and hardenability)," with an appendix "Bibliography on the effect of grain-size on the magnetic properties of steel." (Covering the period 1922 to 1940).

LIST OF SPECIAL REPORTS.

(To 31st December, 1941).

Price stated after each Report.

Special Report No. 1. First Report of the Corrosion Committee. (1931). Price 16/-. (Members, 10/-.)

Special Report No. 2. Fourth Report on the Heterogeneity of Steel Ingots. (1932). Price 16/-. (Members, 10/-.)

Special Report No. 3. First Report of the Steel Castings Research Committee. (1933). Price 10/-. (Members, 5/-.)

Special Report No. 4. Fifth Report on the Heterogeneity of Steel Ingots. (1933). Price 10/-. (Members, 5/-.)

Special Report No. 5. Second Report of the Corrosion Committee. (1934). Price 16/-. (Members, 10/-.)

Special Report No. 6. First Report of the Blast-Furnace Practice Sub-Committee. (1934). Price 10/-. (Members, 5/-.)

NOTE.—The First, Second and Third Reports of the Committee on the Heterogeneity of Steel Ingots were originally printed in the *Journal of the Iron and Steel Institute* as follows :

First Report : 1926, No. I., pp. 39–151.

Second Report : 1928, No. I., pp. 401–547. Price 16/-. (Members, 10/-.)

Third Report : 1929, No. I., pp. 305–376. Price 10/-. (Members, 5/-.)

Reprints of the Second and Third Reports are still available, but the First Report is out of print.

LIST OF TRANSLATIONS.

(To 31st December, 1941.)

Price : Nos. 1 to 27 gratis; others 10/- for the first copy, 5/- for each additional copy of the same translation.

No. 1 (German).   P. BARDENHEUER and G. THANHEISER :   "Investigation of the Metallurgy of the Acid Open-Hearth Process." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1934, vol. 16, No. 17, pp. 189–200).

No. 2 (German).   P. BARDENHEUER : "Investigations concerning the Cast Structure of Steel Ingots." (*Stahl und Eisen*, 1935, vol. 55, Jan. 24, pp. 92–93. (A review of a paper by B. D. ENLUND entitled "Microscopic Studies of Ingot Structures," published in *Jernkontorets Annaler*, 1934, vol. 118, pp. 391–438).

No. 3 (German).   HANS EULER and KURT GUTHMANN : "Sources of Error in Temperature Measurement by Thermocouples." (*Archiv für das Eisenhüttenwesen*, 1935, vol. 9, Aug., pp. 73–90),

No. 4 (German).   F. BOLLENRATH and W. BUNGARDT : "The Thermal Conductivity of Pure Iron and Commercial Steels." (*Archiv für das Eisenhüttenwesen*, 1935, vol. 9, Nov., pp. 253–262).

No. 5 (Russian).   V. N. SVETCHNIKOFF : "The Influence of Added Elements on the Polymorphism of Iron as a Function of their Position in the Periodic System." (Paper read at the meeting of the Scientific-Technical Conference of the Dniepropetrovsk Institute of Metallurgy on June 12th, 1935).

No. 6 (Russian).   V. N. SVETCHNIKOFF and N. S. ALFEROFF : "Investigation of the Alloys of the Fe–C–Mo System." (Paper read before the Conference of the Metallurgical Section of the Dniepropetrovsk District Scientific-Technical Department of Metallurgy on February 29th, 1936).

No. 7 (German).   F. KÖRBER : "The Relationships between the Heat of Formation, the Structure and the Properties of Commercially Important Alloys." (*Stahl und Eisen*, 1936, vol. 56, Nov. 26, pp. 1401–1411).

No. 8 (German).   E. MAURER : "Heat Conductivity of Steels Containing Chromium at High Temperatures." (*Archiv für Eisenhüttenwesen*, 1936, vol. 10, Oct., pp. 145–154).

No. 9 (Russian).   C. MESSERLE : "Oxygen-Enriched Blast in the Blast-Furnace Process." (*Stal*, 1936, No. 7, July, pp. 1–10).

No. 10 (German).   H. WENTRUP : "The Formation of Inclusions in Steel." (*Technische Mitteilungen Krupp*, 1937, vol. 5, June (second number), pp. 131–152).

No. 11 (German).   L. REICHERT : "Roller Straightening Machines." (*Zeitschrift des Vereines deutscher Ingenieure*, 1937, vol. 81, Mar. 27, pp. 385–387).

No. 12 (German).   K. GUTHMANN : "Comparative Measurements of Temperature on Heats of Pig Iron, Cast Iron and Steel." (*Stahl und Eisen*, 1937, vol. 57, Nov. 4, pp. 1245–1248; Nov. 11, pp. 1269–1277).

No. 13 (German).   E. M. H. LIPS and H. A. NIPPER : "The Gating of Castings." (*Giesserei*, 1938, vol. 25, June 3, pp. 265–275).

No. 33 (German). ROBERT DURRER : "The Smelting of Iron Ores by Old and New Methods." (*Stahl und Eisen*, 1940, vol. 60, Oct. 3, pp. 877–880).

No. 34 (German). KARL LÁNG : "Contribution to the Calculation of Rolling Pressure and Rolling Work." (*Stahl und Eisen*, 1916, vol. 36, Jan. 6, pp. 10–17).

No. 35 (German). KAMILLO KONOPICKY : "Refractory Materials containing Chrome Ore." (*Stahl und Eisen*, 1941, vol. 61, Jan. 16, pp. 53–63).

No. 36 (German). ERNST HOWAHR : "The Rolling of Heavy and Medium Plates." (*Stahl und Eisen*, 1941, vol. 61, Jan. 23, pp. 73–83; Jan. 30, pp. 100–107).

No. 37 (German). "The Use of Chromium in the Production of Steel." Part I.—The Oxidation Loss of Chromium in the Basic Open-Hearth Furnace, by MAX HAUCK. Part II.—The Behaviour of Chromium in the Basic Open-Hearth Furnace, by GEORG ROCKROHR. (*Stahl und Eisen*, 1941, vol. 61, Feb. 27, pp. 201–210).

No. 38 (German). FRITZ HARTMANN : "The Physical Behaviour of Ores and Additions in the Blast-Furnace." (*Stahl und Eisen*, 1940, vol. 60, Nov. 14, pp. 1021–1026).

No. 39 (German). FRIEDRICH EISERMANN : "The Production of Mild Steels in the Acid Open-Hearth Furnace with particular Consideration of the Melting Practice." (*Stahl und Eisen*, 1940, vol. 60, July 18, pp. 629–634).

No. 40 (German). HANS SCHRADER : "Experience in the Application of the Magnetic Powder Process of Testing for Cracks." (*Stahl und Eisen*, 1940, vol. 60, July 18, pp. 634–640; July 25, pp. 655–658).

No. 41 (German). "Measures of Works Economics for Increasing the Capacity of the Iron and Steel Industry." Part I. by RICHARD RISSER. Part II. by WERNER SCHÜTTE. (*Stahl und Eisen*, 1940, vol. 60, Nov. 28, pp. 1069–1075; Dec. 5, pp. 1107–1113).

No. 42 (Russian). K. GINZBURG and N. UL'MAN : "Determination of the Resistance to Deformation in Dynamic Upsetting and of the Coefficient of External Friction for Several Structural Steels." (*Stal*, 1939, No. 6, pp. 26–28).

No. 43 (Russian). YA. GALLAY : "Lignostone Bearings for Rolling Mills." (*Stal*, 1939, No. 4–5, pp. 45–49).

No. 44 (German). H. HOUDREMONT, W. BENNEK and H. WENTRUP ; "The Exploration and Combating of the Intercrystalline Corrosion of Unalloyed Steels." (*Stahl und Eisen*, 1940, vol. 60, Aug. 29, pp. 757–763; Sept. 5, pp. 791–797).

No. 45 (German). P. HERASYMENKO and P. DOMBROWSKI : "Hydrogen Equilibria in Steelmaking." (*Archiv für das Eisenhüttenwesen*, 1940, vol. 14, Sept., pp. 109–115). (Made available through the courtesy of Dr. W. T. Griffiths of the Mond Nickel Co., Ltd.).

No. 46 (Russian). M. M. KARNAUKHOV : "Present-Day Wrought-Iron Production Practice." (*Metallurg*, 1940, No. 2, pp. 16–20).

No. 47 (Russian). N. M. CHUYKO : "Theory of the Absorption of Hydrogen in the Electric Furnace Melting of Steel." (*Teoriya i Praktika Metallurgii*, 1938, No. 5, pp. 31–37).

No. 48 (German). H. CORNELIUS : "The Properties of Manganese Heat-Treatable Steels containing other Alloy Additions." (*Stahl und Eisen*, 1940, vol. 60, Nov. 28, pp. 1075–1083).

No. 49 (German). H. BENNEK and G. KLOTZBACH : "Effect of the Hydrogen Content, Hydrogen Permeability and Hydrogen Solubility on Flake Formation in Steel." (*Stahl und Eisen*, 1941, vol. 61, June 19, pp. 597–606; June 26, pp. 624–630).

No. 50 (Russian). A. S. BRUK : "Coke Quality and the Working of Blast-Furnaces." (*Koks i Khimiya*, 1939, No. 10–11, pp. 7–9).

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PREFACE.

THE present volume contains one report and eleven papers presented at the Autumn Meeting held in London on November 25th, 1941; of these, six were presented under the auspices of the Joint Research Committees of the Institute and the British Iron and Steel Federation, and one is a record of a research carried out with the aid of a grant from the Andrew Carnegie Research Fund. The discussions and correspondence to which these gave rise are also included, together with the authors' replies. In addition, further discussion and the authors' replies on two papers included in the No. I. volume for the year will be found in the present book. Lastly, an erratum to the reply to correspondence on a paper published in an earlier volume is also printed here.

The foregoing papers, together with the Minutes of Proceedings of the Meeting and biographical notes on deceased Members are included in Section I. of this Journal. Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title-page are inserted lists of Bibliographies, Special Reports and Translations issued by the Institute.

4, GROSVENOR GARDENS,
        LONDON, S.W.1.
    February, 1942.

CONTENTS.

LIST OF PLATES.

ABBREVIATIONS USED IN TEXT.

Å.	Ångström unit(s).	kg.	kilogramme(s).
A.C.	air-cooled; alternating current.	kg.cal.	kilogramme-calory; -calories.
A.H.	air-hardened.	kg.m.	kilogramme-metre(s).
amp.	ampère(s).	km.	kilometre(s).
amp.hr.	ampère-hour(s).	kVA.	kilovolt-ampère(s).
atm.	atmosphere(s) (pressure).	kW.	kilowatt(s).
Bé.	Baumé (scale).	kWh.	kilowatt-hour(s).
b.h.p.	brake horse-power.	lb.	pound(s).
B.o.T.	Board of Trade.	L.F.	low-frequency.
B.Th.U.	British thermal unit(s).	m.	metre(s).
C.	centigrade (scale).	m.amp.	milliampère(s).
cal.	calory; calories.	mV.	millivolt(s).
c.c.	cubic centimetre(s).	max.	maximum.
c.d.	current density.	mg.	milligramme(s).
c.g.s.	centimetre-gramme-second unit(s).	min.	minimum; minute(s).
		ml.	millilitre(s).
cm.	centimetre(s).	mm.	millimetre(s).
coeff.	coefficient.	m.m.f.	magnetomotive force.
const.	constant(s).	N.	normal (solution).
c.p.	candle-power.	N.T.P.	normal temperature and pressure.
cu.	cubic.		
cwt.	hundredweight(s).	O.H.	open-hearth; oil-hardened.
D.C.	direct current.	O.Q.	oil-quenched.
dia.	diameter(s).	oz.	ounce(s).
dm.	decimetre(s).	p.d.	potential difference.
e.m.f.	electromotive force.	pH	hydrogen-ion concentration.
F.	Fahrenheit (scale).		
ft.	foot; feet.	r.p.m.	revolutions per minute.
ft.lb.	foot-pound(s).	sec.	second(s).
g.	gramme(s).	sp. gr.	specific gravity.
gal.	gallon(s).	sq.	square.
H.F.	high-frequency.	T.	tempered.
h.p.	horse-power.	temp.	temperature.
h.p.hr.	horse-power-hour(s).	V.	volt(s).
hr.	hour(s).	VA.	volt-ampère(s).
in.	inch; inches.	Wh.	watt-hour(s).
in.lb.	inch-pound(s).	W.Q.	water-quenched.
K.	absolute temperature (Kelvin scale).	yd.	yard(s).
		°	degree(s).

MINUTES OF PROCEEDINGS
AND PAPERS OF
THE IRON AND STEEL INSTITUTE.

———————

AUTUMN MEETING
1941

———————

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

AUTUMN MEETING IN LONDON, 1941.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Tuesday, November 25, 1941, at 2.45 P.M., the PRESIDENT (Mr. John Craig, C.B.E., D.L.) being in the Chair.

The Minutes of the previous Meeting were taken as read and signed.

CHANGES ON THE COUNCIL.

President-Elect for 1942.—The PRESIDENT (Mr. John Craig) said it gave him much pleasure to announce that Mr. James Henderson had been nominated unanimously by the Council for election as President at the Annual Meeting to be held in 1942. He congratulated Mr. Henderson on being nominated for a position which he was well qualified to occupy.

Honorary Treasurer.—The PRESIDENT announced that the Hon. R. G. Lyttelton had accepted the Council's invitation to succeed Mr. Henderson as Honorary Treasurer.

Nomination of a Vice-President and Members of Council.—The PRESIDENT announced that the Council had nominated Dr. Andrew McCance (a Director of Messrs. Colvilles, Ltd.) to be a Vice-President of the Institute and had invited Professor J. H. Andrew, D.Sc. (Sheffield University), and Mr. N. H. Rollason (Managing Director of Messrs. John Summers & Sons, Ltd.) to become Members of Council.

Honorary Members of Council.—The PRESIDENT announced that the Council had decided to invite the Presidents of the Sheffield Society of Engineers and Metallurgists and of the Sheffield Metallurgical Association to become Honorary Members of Council.

Vice-Presidents and Members of Council retiring in 1942.—The SECRETARY (Mr. K. Headlam-Morley) announced that, in accordance with Bye-Law No. 10, the following Vice-Presidents and Members of Council would retire in rotation at the Annual General Meeting in 1942:

Vice-Presidents: Dr. C. H. Desch, F.R.S., Dr. W. H. Hat-
field, F.R.S., and Sir William J. Larke,
K.B.E.

Members of Council: Mr. W. J. Brooke, Mr. E. J. Fox, Mr. J.
Sinclair Kerr, Dr. T. Swinden and Mr.
A. B. Winder.

HONORARY MEMBER.

The PRESIDENT announced that the Council at their Meeting
that morning had unanimously decided to invite Mr. Walter S.
Tower, President of the American Iron and Steel Institute, to be
an Honorary Member of The Iron and Steel Institute.

ANDREW CARNEGIE RESEARCH GRANT FOR 1942.

The SECRETARY announced that the following renewal of a
Carnegie Scholarship grant had been awarded by the Council:

M. BALICKI (University College, Swansea).—£100 for 1942
in aid of the continuation of a research on the softening and
recrystallisation phenomena of cold-worked mild steels.

BALLOT FOR THE ELECTION OF NEW MEMBERS AND ASSOCIATES.

Mr. G. R. BASHFORTH (Hon. Member of Council; Round Oak
Steel Works, Ltd., Brierley Hill, Staffs.) and Mr. J. A. JONES (Messrs.
Samuel Fox & Co., Ltd., Stocksbridge, near Sheffield) were appointed
scrutineers of the ballot for the election of new Members and Asso-
ciates, and later they reported that the following fifty-six Members
and twenty-five Associates had been elected:

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WOODHEAD, JACK HARPER	Sheffield.

COLLABORATION OF POLISH METALLURGISTS.

Dr. Eng. W. WRAZEJ (Poland) said that for him this was an exceptional occasion; for the first time he was able to attend a Meeting of The Iron and Steel Institute, although he had been a Member since 1933. He wished to speak on behalf of his Polish colleagues who were also Members of the great Iron and Steel Institute as well as on his own behalf, and to offer to the Institute his best wishes for success in all its undertakings, and for the success of the present Meeting. Polish technicians, whether in uniform or not, wished to stand firm in the ranks with their British colleagues, and to strain every effort necessary for victory.

Having under consideration the concentration of effort for the common goal, the Institute of Technical Research, General Staff of

the Polish Army, had been created. It comprised the best Polish technicians, who represented all branches of science, including metallurgy. Looking at the work of this Institute of Technical Research, he saw the effort made by his colleagues who had the opportunity of collaborating with British industry, and he saw how they did their best to carry out the demands and necessities of the moment. In addition to those who were collaborating with British industry, however, many good Polish specialists waited for the opportunity to co-operate in working for the common goal.

It was his opinion that at such an important moment as the present, the hands and brains of these qualified men, good friends of the British nation, should be suitably utilised. He was not asking for any kind of remuneration for them; he asked solely that they should be allowed in common to create the union which would support the mutual life of their two nations in the future. Neither a visit nor mutual social life could found such a friendship and such a knowledge of each other as could be won in a common workshop or trench in wartime, when the two nations were allied for better or for worse. The Poles felt the deepest sentiment for all their friends, because such was their Polish nature, and in their friendship they were frank and honest.

He hoped that his few but sincere words, addressed to his British colleagues, would be well understood, and that they would stretch out their hands to join with their Polish colleagues more closely than ever in the common effort, of which the final result could and must be victory. (*Applause.*)

The PRESIDENT (Mr. John Craig) assured Dr. Wrazej that his British fellow-members entirely shared his sentiments. Continuing, he said that if he might be allowed a personal word, it would be that his own Company had had experience of the help which could be afforded and the ability which could be displayed by some Polish members who had joined their staff in recent months and who were rendering excellent service—service which was highly appreciated not only by the directors of the Company but also by many of their workmen, who had been impressed by the efficiency and the enthusiasm of these Polish technicians.

INTRODUCTORY REMARKS BY THE PRESIDENT.

The PRESIDENT (Mr. John Craig) went on to say that at such a short Meeting he did not propose to make a lengthy speech.

He would like to say, however, that although the Institute had not been able to function as fully as would have been the case in normal circumstances, or take such an active part in organising lectures and debates, it must not be thought that it had been neglecting its work. Under the inspiring leadership of Dr. Hatfield, the Research Committees of the Institute were to-day fully engaged on work of the highest national importance, and were rendering

great service to the country by the work which they were doing and by the help which they were giving to all branches of our great Fighting Forces. For that alone the Institute deserved well of the industry and of the country, because of the ability and the help which it was able to place at the disposal of the country as a whole.

He had said before that in his view this was the great opportunity of the scientists to demonstrate their real worth. In ordinary times they were sometimes looked on as non-producers and sometimes as a burden on industry, but to-day they were valued and appreciated, because they were showing the industry better ways of doing many a difficult task.

For the rest, the Institute must remain fairly quiet at present, but there was one feature to which he must make a passing reference. The Council had been gratified by a substantial addition to the membership of the Institute of friends in the industry in America. They had shown their willingness to co-operate, and, if the Institute had lost members elsewhere, it had gained them in a country with whom there could be the closest co-operation in the future. (*Applause.*)

PRESENTATION OF PAPERS.

A list of all the papers included in the programme of the Meeting will be found on the next page; the following were presented for verbal discussion :

" Apparent Relations between Manganese and Segregation in Steel Ingots," by J. H. WHITELEY.

" The Application of Spectrographic Methods to the Analysis of Segregates," by F. G. BARKER, J. CONVEY and J. H. OLDFIELD.

" The Ladle Cooling of Liquid Steel," by T. LAND.

The PRESIDENT, on behalf of the Council, thanked the authors for their papers. There was still, he said, plenty to learn in the steel trade; young men need not think that they would exhaust the subject in their lifetime, and every paper seemed to end with " To be continued in our next."

He thanked the Members present for their attendance, and said he knew how difficult it was for many of them to spare time for the purpose, but he hoped that in this way the industry was keeping alive the spirit of enquiry and a thirst for knowledge among the younger Members, while the older Members were able to contribute from their experience, in such a way as would enable the industry to continue to prosper. He hoped that The Iron and Steel Institute would continue to serve the industry in the future as it had in the past.

Complete List of Papers Presented at the Autumn Meeting in London, 1941.

J. H. AWBERY : " A Note on the Theory of Quenching." (Paper No. 3/1941 of the Alloy Steels Research Committee (submitted by Dr. E. Griffiths, F.R.S., through the Thermal Treatment Sub-Committee).)

F. G. BARKER, J. CONVEY and J. H. OLDFIELD : " The Application of Spectrographic Methods to the Analysis of Segregates." (Paper No. 7/1941 of the Heterogeneity of Steel Ingots Committee.)

L. W. BOLTON : " A Study of Some of the Factors Affecting the Resistance of Cast Iron to Deflection under Load at High Temperatures." (Andrew Carnegie Research Report.)

A. J. BRADLEY, F.R.S., and H. J. GOLDSCHMIDT : " An X-Ray Investigation of Iron-Nickel-Chromium Alloys."

B. CHALMERS and W. E. HOARE : " The Longitudinal Ridged Structure in the Tin Coating of Tinplate."

E. GREGORY and J. H. WHITELEY : " Examination of a High-Sulphur Free-Cutting Steel Ingot." (Paper No. 6/1941 of the Heterogeneity of Steel Ingots Committee.)

T. P. HOAR, T. N. MORRIS and W. B. ADAM : ' " The Influence of the Steel Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers.—Part II."

T. LAND : " The Ladle Cooling of Liquid Steel." (Paper No. 1/1941 of the Steel Castings Research Committee (submitted by Mr. D. A. Oliver).)

A. G. QUARRELL : " Note on the Resistance to Furnace Atmospheres of Heat-Resisting Steels." (Paper No. 2/1941 of the Alloy Steels Research Committee.)

T. SWINDEN and J. H. CHESTERS : " Dolomite Bricks for Use in Steelworks."

J. H. WHITELEY : " Apparent Relations between Manganese and Segregation in Steel Ingots." (Paper No. 8/1941 of the Heterogeneity of Steel Ingots Committee.)

" A Co-operative Investigation of the Factors Influencing the Durability of the Roofs of Basic Open-Hearth Furnaces." A Report by the OPEN-HEARTH REFRACTORIES JOINT PANEL (working under the ægis of the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association).

> FOREWORD. By T. Swinden, D.Met., and A. T. Green, F.I.C.
> SECTION I.—The Manufacture of the Roof Bricks and their Properties before Use. By T. R. Lynam, F.G.S., J. H. Chesters, Ph.D., B.Sc., and T. W. Howie, B.Sc.
> SECTION II.—The Furnace and Pyrometer Installation. By J. E. Doyle, W. J. Collins and J. E. Pluck.
> SECTION III.—The Furnace Campaign.
>> Part 1.—Conditions of Service with Particular Reference to the Temperature Gradient through the Roof. By A. E. Dodd, M.Sc.(Lond.).
>> Part 2.—The Nature of the Dust in the Atmosphere in a Basic Open-Hearth Furnace. By J. H. Chesters, Ph.D., B.Sc., and W. Hugill, M.Met., F.R.M.S., A.R.P.S.
>> Part 3.—Draught Conditions during the Campaign. By J. E. Doyle and W. J. Collins.
>> Part 4.—Details of Repairs to the Roof during the Campaign. By J. E. Pluck.
> SECTION IV.—Examination of Samples taken from the Roof at the End of the Campaign. By J. H. Chesters, Ph.D., B.Sc., B. W. Methley, F.I.C., T. R. Lynam, F.G.S., T. W. Howie, B.Sc., and A. E. Dodd, M.Sc.(Lond.).
> SECTION V.—The Results of X-Ray Studies of the Raw Material and of Used Silica Brick from the Open-Hearth Furnace Roof. By A. H. Jay, Ph.D., F.Inst.P.
> SECTION VI.—The Microstructure of Used Roof Bricks. By W. Hugill, M.Met., F.R.M.S., A.R.P.S.
> SECTION VII.—General Conclusions.

VOTE OF THANKS TO THE PRESIDENT.

The Hon. RICHARD G. LYTTELTON (Member of Council; Messrs. Guest, Keen and Nettlefolds, Ltd., London) proposed a cordial vote of thanks to the President for his conduct in the Chair. The Members, he said, very much appreciated the atmosphere which the President had created at this and other Meetings, and which materially assisted in promoting the interesting discussions which had been held under his presidency.

The vote of thanks was carried with acclamation, and was briefly acknowledged by the President.

The proceedings then terminated.

EXAMINATION OF A HIGH-SULPHUR FREE-CUTTING STEEL INGOT.

By E. GREGORY, Ph.D., M.Sc., F.I.C. (The Park Gate Iron and Steel Co., Ltd., Rotherham), and J. H. WHITELEY, F.I.C. (The Consett Iron Co., Ltd., Consett, Co. Durham).

(Figs. 3 to 46 = Plates I. to VIII.)

Paper No. 6/1941 of the Committee on the Heterogeneity of Steel Ingots.

Summary.

An ingot of steel of high sulphur content was subjected to a detailed examination in regard to heterogeneity, and an examination of the inclusions in it was made. The experimental evidence recorded in Part I., by Gregory, indicates that the degree of segregation is less than might have been expected and is actually of a similar order to that found to occur in steel ingots of more " normal " sulphur contents. It is shown that, in the ingot examined, the elements which tend to segregate to the least extent are carbon, manganese, phosphorus and nitrogen, and that the elements which exhibit the greatest variation are sulphur, oxygen and hydrogen; the last three elements tend to segregate, but independently, although there is some indication, from both chemical analysis and microscopical examination, of inverse segregation as regards sulphur and oxygen, *i.e.*, a high sulphur content is accompanied by a relatively low oxygen content and *vice versa*. Attention is drawn to the fact that when the oxygen content is low, the inclusions are apparently homogeneous, whereas in regions relatively rich in oxygen the inclusions exhibit duplex structures. It is also shown that the " major " inclusions have spherical or globular forms, indicating some degree of emulsification before the freezing of the steel, and the view is expressed that this has some connection with the excellent rolling properties of the steel.

In Part II. Whiteley describes the examination of the inclusions at three positions in the ingot. As was to be expected, sulphide particles were very numerous. Both large and small consisted of MnS, except in highly segregated areas, where FeS greatly predominated. The coalescence of sulphides has been studied. It is shown that, on heating the steel to within the liquidus-solidus range, the MnS inclusions were replaced by groups of minute particles containing much FeS. In cooling, two distinct arrangements of these particles occurred, both resembling eutectic formations. Owing to the presence of local areas rich in FeS, the diffusion of manganese in the steel up to 1350° C. has been investigated, using both pearlite coalescence and the change of FeS to MnS as indicators. The rate was found to be slow. The fact that steel of this kind rolls well, notwithstanding its very high sulphur content, leads to a consideration of possible factors which influence cracking in casting, on the basis of which an explanation is suggested. Besides the sulphides there was another type of inclusion. It was composed of globules,

sometimes very large and often complex in structure. Within them were usually rounded MnS particles and an occasional idiomorphic crystal resembling chromite. Frequently the globules also contained areas of FeO, this compound not being elsewhere observed. The ground-mass in which these inclusions were embedded was eutectiferous in character and translucent owing to a silicate component. Various tests indicated that it belonged to the system fayalite–rhodonite–FeS–MnS–FeO.

INTRODUCTION.

AN ingot of high-sulphur free-cutting steel was supplied to the Committee on the Heterogeneity of Steel Ingots by the Park Gate Iron and Steel Co., Ltd., through the courtesy of Mr. Fred Clements.

The main feature of this steel, which experience has proved to possess excellent free-cutting and other properties, is its exceptionally high sulphur content. The composition generally aimed at lies between the following limits :

Carbon	.	.	.	.	.	0·08 –0·12%
Silicon	.	.	.	.	.	0·04% max.
Sulphur	.	.	.	.	.	0·40 –0·50%
Phosphorus	.	.	.	.	.	0·035–0·045%
Manganese	.	.	.	.	.	1·00 –1·20%

In view of the abnormally high sulphur content of this steel, it was thought that the examination of an ingot of this quality might prove to be interesting and perhaps shed some light on the heterogeneity of steel ingots generally.

The selected ingot was taken from a cast made in a basic-lined open-hearth furnace of 65 tons capacity, and the cast analysis (H952) was as follows :

	C. %.	S. %.	P. %.	Mn. %.
Pit test (1)	0·08	0·466	0·043	1·01
(2)	0·09	0·480	0·043	1·02
Test ingot :—Billet No. 2	0·08	0·462	...	1·07
,, 4	0·08	0·466	0·039	1·07
,, 6	0·09	0·470	...	1·10
,, 8	0·08	0·482	0·044	1·05

In making steel of this quality it is the practice at Park Gate to add most of the sulphur to the bath in the form of ferrous sulphide, in two stages. When the first addition has worked through, a sample is taken, drilled, and rapidly analysed by the combustion method. The second addition of ferrous sulphide is then made and a further sample analysed for sulphur just before tapping. Any final adjustment of the sulphur content is made by the addition of " rock " sulphur to the ladle. By these means close control over the sulphur content of the steel is exercised.

In the cast from which the ingot was selected for detailed examination, the iron content of the tapping slag was 19·4% (the

equivalent of 24·9% of ferrous oxide, FeO).   On this account, taking cognisance of the application of the partition law regarding the relative iron-oxide contents of the molten slag and the metal beneath it, a relatively high oxygen content in the finished solid steel is to be expected.   Incidentally, it may be mentioned that this slag contained 9·82% of P_2O_5.

PART I.—Investigation of the Heterogeneity of the Ingot.*

By E. GREGORY, Ph.D., M.Sc., F.I.C. (Rotherham).

The selected ingot weighed 46 cwt. and was teemed into a mould having the internal dimensions shown in Fig. 1.   After sectioning down the middle, the surface of one half of the ingot was prepared for sulphur-printing and then for macro-etching; the other half was cut up for micro-examination and chemical analysis at the " standard " positions laid down by the Ingots Committee.   The chemical analyses, in regard to the usual elements, were carried out
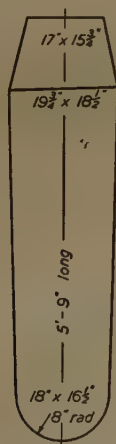
FIG. 1.—Dimensions of Ingot Examined.

in the laboratories of the Park Gate Iron and Steel Co., Ltd. The oxygen, nitrogen and hydrogen determinations were carried out, through the courtesy of Dr. W. H. Hatfield, F.R.S., Chairman of the Committee, in the Brown-Firth Research Laboratories, who also undertook the task of preparing the sulphur- and macro-prints reproduced in Figs. 3 and 4.   Anyone with experience in making sulphur-prints of high-sulphur free-cutting steels will fully appreciate

* Received January 31, 1941.

the difficulties of obtaining satisfactory sulphur-prints from a steel so rich in sulphur as the ingot under examination and the excellence of the print reproduced in Fig. 3 is a striking tribute to the skill and technique of those who prepared the original in the Brown-Firth
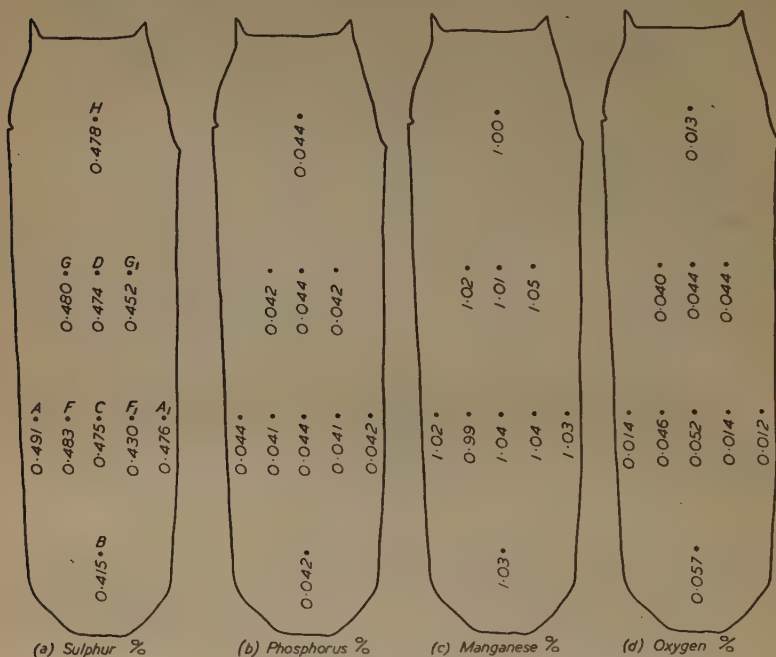
FIG. 2.—Analyses at the Standard Positions on the Ingot Section.

TABLE I.—*Analyses at the Standard Positions in the Ingot.*

Position.	C. %.	Si. %.	S. %.	P. %.	Mn. %.	O. %.	N. %.	H. %.
B	0·07	0·005	0·415	0·042	1·03	0·057	0·0023	0·00036
A	0·08	0·009	0·491	0·044	1·02	0·014	0·0022	0·00037
F	0·065	...	0·483	0·041	0·99	0·046	0·0028	0·00059
C	0·08	...	0·475	0·044	1·04	0·052	0·0025	0·00069
F_1	0·07	...	0·430	0·041	1·04	0·014	0·0029	0·00057
A_1	0·07	...	0·476	0·042	1·03	0·012	0·0020	0·00040
G	0·075	0·005	0·480	0·042	1·02	0·040	0·0025	0·00042
D	0·08	...	0·474	0·044	1·01	0·044	0·0021	0·00052
G_1	0·08	...	0·452	0·042	1·05	0·044	0·0023	0·00047
H	0·08	Trace	0·478	0·044	1·00	0·013	0·0026	0·00041

Research laboratories. The concentration of the sulphuric acid used for this purpose was approximately 0.1%.

The analytical results obtained for the standard positions (indicated in Fig. 2 (*a*)) are recorded in Table I., and the sulphur, phosphorus, manganese and oxygen figures are charted in Fig. 2.

A microscopic examination of both etched and unetched specimens cut from the ingot was conducted, and some of the relevant micrographs are shown in Figs. 5 to 14.

The nature of the inclusions has been intensively studied by Mr. J. H. Whiteley; his conclusions and views are given in Part II. of this paper.

Discussion of the Results.

From the examination of the sulphur-print, Fig. 3, it is clear that there is no greater relative degree of segregation in regard to sulphur than in a steel regarded as having a " normal " sulphur content. Thus, the analytical results show a variation in sulphur content from 0.415 to 0.491%. Taking the mean as 0.453%, this indicates a degree of segregation amounting to $\pm 8.4\%$ of the actual average sulphur content. In a steel containing, say, an average of 0.05% of sulphur, this degree of segregation would result in areas containing 0.054 and 0.046% of the element, an indicated degree of segregation which is often much less than that found in practice. It would seem, therefore, that the actual mechanism causing segregation is the same in both high- and low-sulphur steels, and, furthermore, Fig. 3 may be regarded as a picture of the distribution of the element in almost any steel produced on a commercial scale. (In electric-arc-furnace steels, however, containing exceedingly low proportions of sulphur, the pattern illustrated would not be expected, since, if the elements which normally tend to segregate are nearly absent, the segregation must be reduced to an absolute minimum.)

It is of interest to note the relatively slight degrees of phosphorus and manganese segregation, a somewhat unexpected result.

The greatest degree of segregation is in regard to oxygen, and, curiously enough, this seems to be entirely independent of the manganese, but there is some indication that the oxygen and sulphur segregations are inverse to each other. From this it may be concluded that sulphur, as well as manganese, plays an important part in the ultimate degree of deoxidation.

So far as the nitrogen contents are concerned, the degree of heterogeneity is relatively small. The hydrogen segregation is definitely more marked than that of the nitrogen, but bears no relation to the oxygen segregation, indicating that in the presence of iron the equilibrium position for the reaction $2H_2O \rightleftharpoons 2H_2 + O_2$ at the temperature of freezing steel lies well to the right, whence it follows that the oxygen and hydrogen contents are independent of each other and proportional only to their partial vapour-pressures at the actual period when solidification occurs.

At positions H and near the outside of the ingot the inclusions, both large and small, are apparently quite homogeneous, whereas the larger inclusions in the interior of the ingot possess duplex structures; in some cases these inclusions have the appearance of eutectics and in others the lighter constituent is decidedly dendritic in nature. From the results of the analyses given in Table I. it is clear that, so far as the larger inclusions are concerned, their homogeneity, or otherwise, is largely a question of oxygen contents. When the oxygen content is low the inclusions apparently consist of a single constituent, but with higher oxygen contents their structures are duplex in nature. From this it may be inferred that the lighter constituent in the micrographs shown is an oxide, or an oxide-sulphide complex relatively rich in oxygen, and the darker constituent a solid solution of iron and manganese sulphides containing little or no oxygen. In the regions in which large homogeneous inclusions are found it may be suggested that practically the whole of the oxygen is contained in the ferrite matrix in which the inclusions are embedded, since it must be appreciated that the oxygen determinations were conducted on pieces of steel the dimensions of which were very large compared with those of the contained inclusions. On the other hand, since duplex structures are apparently associated with general high oxygen contents, it may be assumed that the actual oxygen contents of these inclusions exceed the values indicated in Table I.

Notwithstanding the duplex nature of such inclusions, they appear to exert no detrimental effects on the rolling properties of the steel. Indeed, it may be stated that rolling difficulties, within the author's experience, with steel of the quality under consideration are definitely less than with steels of the more normal high-sulphur type containing lower proportions of sulphur. In view of the fact that the inclusions in the present ingot exist in spherical or globular forms instead of as films along the crystal boundaries, the excellent rolling properties of this steel are not unexpected. During the subsequent rolling of these ingots the essential change which occurs in the nature of the duplex inclusions is their elongation into threads. The duplex structure is often retained in the rolled bloom, billet or bar, although no evidence has been obtained, after rolling, of the persistence of dendritic or eutectic structures.

The spherical forms of the larger inclusions shown in Figs. 10 to 13 are of particular interest, since these indicate that some degree of emulsification occurred prior to solidification, whereas it may be suggested that the smaller inclusions, in view of their somewhat irregular shapes, were formed either during or after the solidification of the molten steel.

Unfortunately, at the moment, there appears to be no absolutely reliable method of analysing the inclusions in order to determine definitely their constitutions, but the possibilities of electrographic micro-chemical analysis and of spectrographic analysis have not

been overlooked, and these methods are receiving attention.   Meanwhile, the problem of identifying the constituents of the inclusions has been tackled from the microscopical point of view by Mr. J. H. Whiteley, whose findings are given in Part II. below.

A Member of the Committee has drawn attention to the eccentricity of the columnar zone shown in the macro-print (Fig. 4). This eccentricity is readily explained by the position of the ingot relative to the other ingots in the casting pit.

PART II.—Examination of the Inclusions in the Ingot.*

By J. H. WHITELEY, F.I.C. (Consett, Co. Durham).

Three pieces weighing about $1\frac{1}{2}$ oz. each were received for the investigation of their inclusion contents.   The positions in the ingot from which they were taken are stated in Table II.; the letters refer to the analytical positions that have been standardised by the Committee on the Heterogeneity of Steel Ingots, as indicated in Fig. 2 (*a*) of Part I.

TABLE II.—*Positions from which Samples were taken.*

Piece No.	Position where cut.
1	Near edge along the GDG_1 axis of the ingot.
2	Near G, *i.e.*, about half way to the centre.
3	Close to H, *i.e.*, at the base of the head.

A preliminary survey of prepared sections under the microscope showed that all three pieces contained very numerous dove-grey inclusions.   For the most part they were rounded in shape but their sizes varied rather widely, as can be seen from a typical group in Fig. 17.   Generally these particles were opaque, though occasionally one was observed to be translucent, and in every such instance the internal reflection had a reddish tint.   In view of the high sulphur content of the steel there could be little doubt that these inclusions, both opaque and translucent, were a sulphide, and since they had the usual colour of MnS were provisionally considered to be that compound.   Yet not entirely so, for, under a high magnification, some were seen to be composite in character, having at their margins films of a dark glassy substance.

Besides these very numerous MnS inclusions another type was present, although in much less quantity.   Inclusions of this kind were invariably globular in shape and often complex in structure. Some were outstandingly large, a diameter of 0·2 mm. being by no means uncommon.   Embedded in the ground-mass of many of these globules and giving them a striking appearance were

* Received March 10, 1941.

several rounded opaque particles of exactly the same colour as the MnS inclusions. An example of medium size is included in Fig. 16, while another is given in Fig. 46. This complex type of inclusion occurred by far the most frequently in sample No. 2; it was seldom encountered in samples Nos. 1 and 3, and, in order to give some idea of this difference, the approximate number per cubic inch in each sample was calculated from the number visible at a magnification of 100 in an area of $\frac{1}{5}$ in. square. The results are recorded in Table III., together with the oxygen contents of the samples as determined by Dr. W. H. Hatfield. It will be seen that there is a definite correspondence between the two sets of figures. The large amount of oxygen in sample No. 2 was apparently connected with the high content of complex globules—as further evidence, to be given later, will also indicate—and, since similar large percentages of oxygen were found at all the interior standard positions except F_1 (*see* Table I., Part I.), the inference may be drawn that these globules were equally numerous throughout the central part of the ingot.

TABLE III.—*Complex Particle Counts and Oxygen Contents.*

Sample No.	Composite Particles Observable at × 100.	Oxygen in Sample. %.
1	27	0·014
2	6000	0·040
3	8	0·013

Thus the inclusions observable in the three sections could be placed in two classes, one consisting presumably of MnS and the other of the complex globules. The two will now be considered in detail, and it will be convenient to take the sulphide first. Now the ratio of manganese to sulphur in MnS is 1·72, and since the average ratio in the steel was 2·20, it was clear that at any rate a preponderance of the sulphur could exist in that form. In ordinary steels MnS inclusions are easily recognisable. They have a dove-grey tint, which turns a lighter blue when the surface is heat-tinted to a golden brown, and when viewed under an oil-immersion lens they show a distinct translucency, the reflection being almost white. The only other compound which might be mistaken for MnS is FeO (including MnO) since it has a similar colour. MnS, however, is a shade lighter, especially when heat-tinted, and is usually much less opaque. Moreover, FeO is almost invariably associated with both MnS and FeS, since the three substances are mutually soluble to a large extent in the liquid state. On freezing, the well-known oxide-sulphide eutectic appears, the occurrence of which in steel is a sure indication of the presence of FeO. Unfortunately, the eutectic, especially that of MnO–MnS, coalesces rather quickly and so the formation may not be in evidence in slowly

PLATE I.
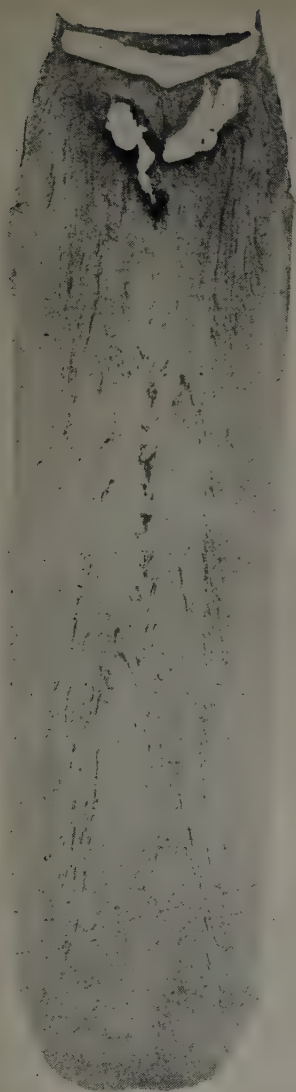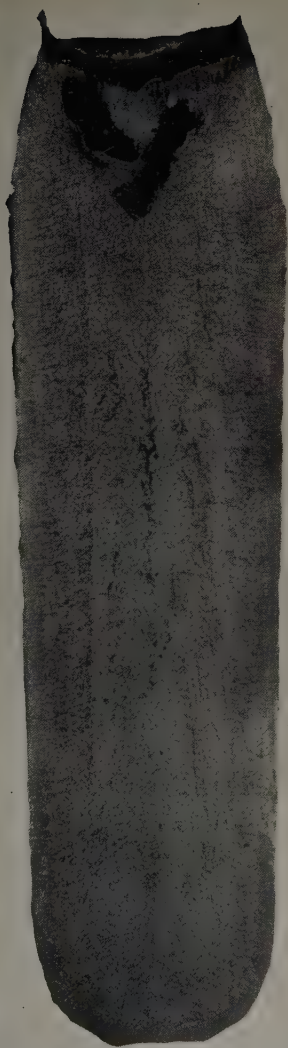
FIG. 3.—Sulphur Print.   FIG. 4.—Macro-Etched Surface.

FIGS. 3 and 4.—Ingot of High-Sulphur Free-Cutting Steel.

PLATE II.
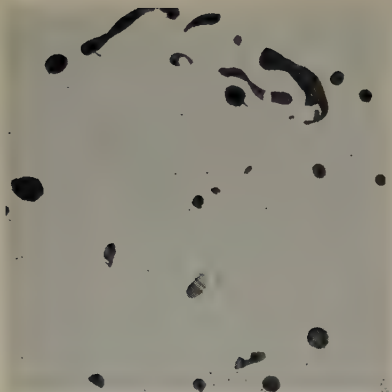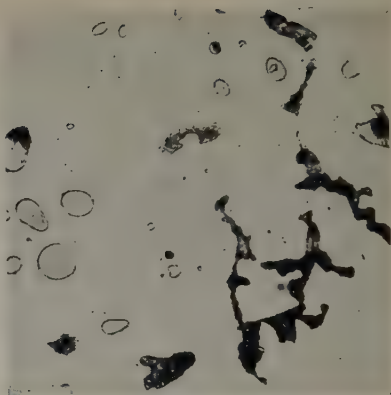
Fig. 5.—Unetched. × 150.   Fig. 6.—Etched. × 150.
Figs. 5 and 6.—Microstructures at Position *H*.
Sulphur = 0·478%. Oxygen = 0·013%.
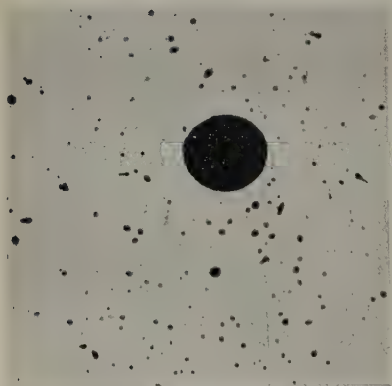
Fig. 7.—Unetched. × 150.   Fig. 8.—Unetched. × 150.
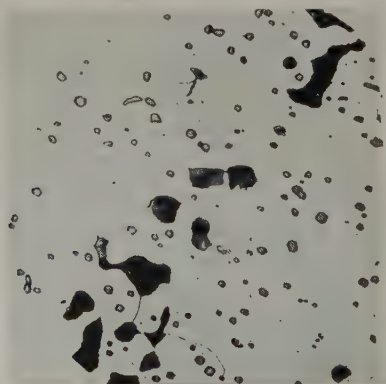
Fig. 9.—Etched. × 150.
Figs. 7 to 9.—Microstructures at a Point between the Edge and Position *G*. No actual analysis done at this
point, but the figures obtained at position *A* are :—
Sulphur = 0·491%. Oxygen = 0·014%.

PLATE III.
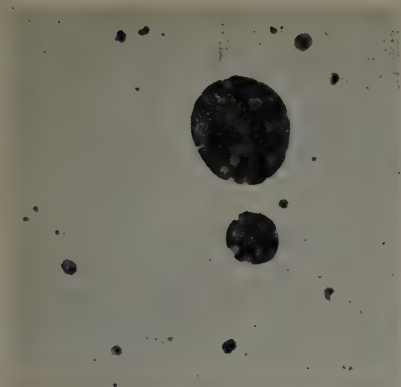
Fig. 10.—Unetched. × 150.
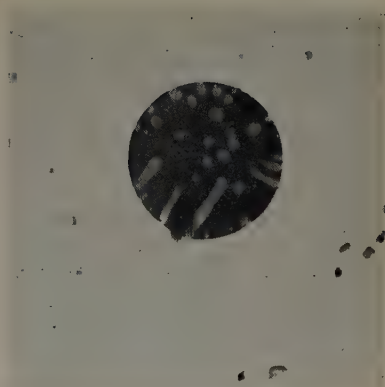
Fig. 11.—Unetched. × 150.

Fig. 12.—Unetched. × 150.
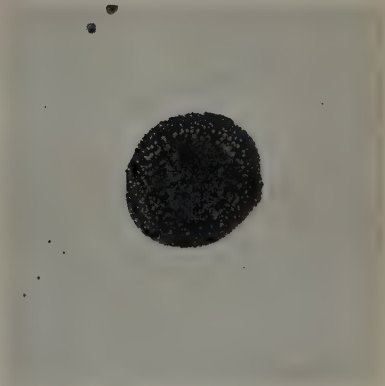
Fig. 13.—Unetched. × 150.
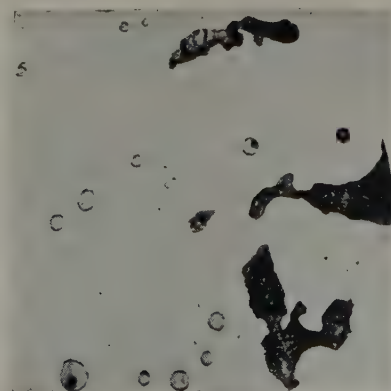
Fig. 14.—Etched. × 150.

FIGS. 10 to 14.—Microstructures at a Point between Positions D and G_1.
Sulphur at D = 0·474%. Sulphur at G_1 = 0·452%. Oxygen at D and G_1 = 0·044%.

[*Gregory & Whiteley.*]

PLATE IV.
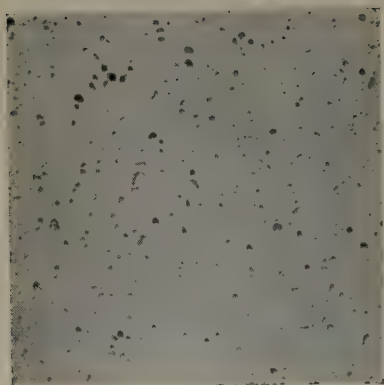
FIG. 15.—Inclusions in Sample No. 1. × 55.
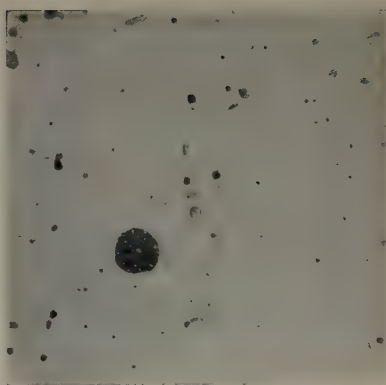
FIG. 16.—Inclusions in Sample No. 2. × 55.
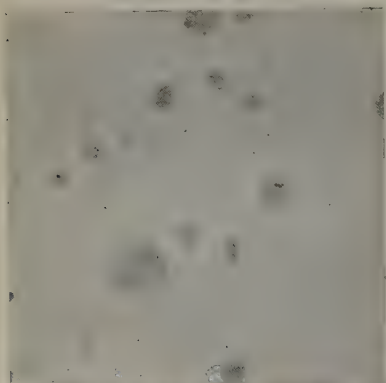
FIG. 17.—MnS in Sample No. 2. × 180.
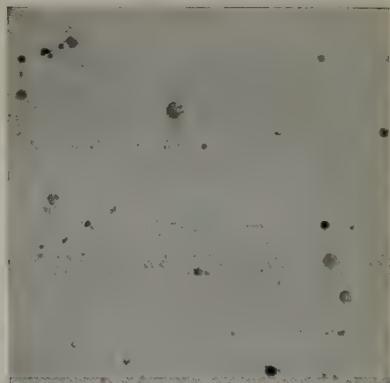
FIG. 18.—Inclusions in Piece A. × 55.
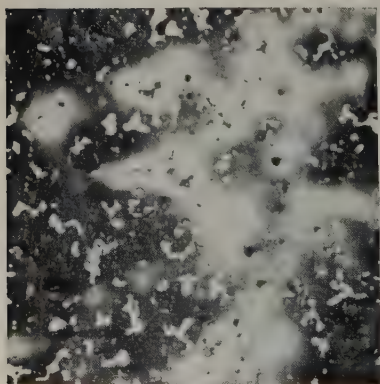
FIG. 19.—Segregate in Sample No. 2. Cupric etch. × 30.
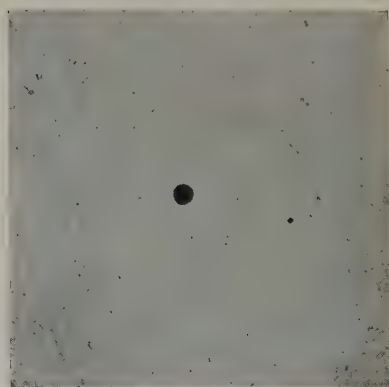
FIG. 20.—Inclusions in Piece B. × 55.

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PLATE V.
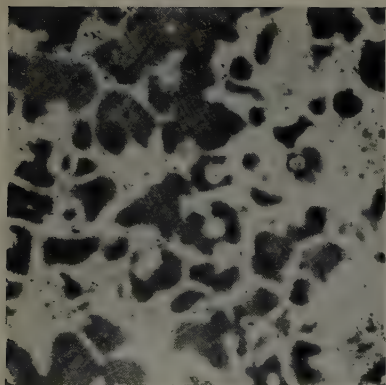
FIG. 21.—Piece *B*, cupric etch.   × 55.
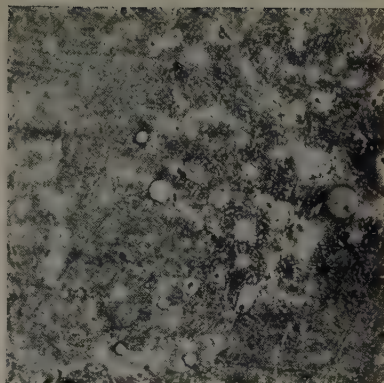
FIG. 22.—Piece *A*, cupric etch.   × 55.
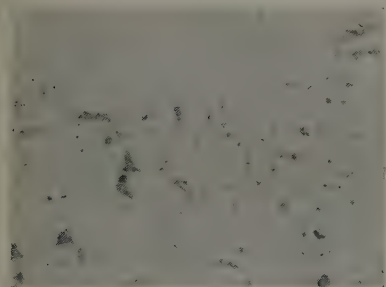
FIG. 23.—Primary Sulphide Formation in Piece *B*.
× 260.
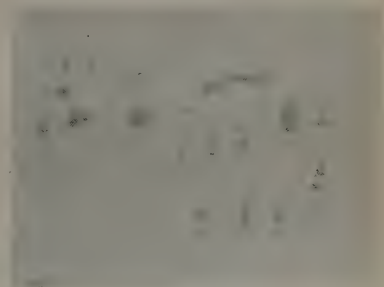
FIG. 24.—Primary Sulphide Formation in Piece
A.   × 450.
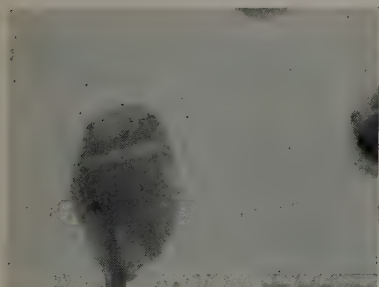
FIG. 25.—FeS–MnS Mixture Inclusion in
Segregate.   × 870.

FIG. 26.—Secondary Sulphide Formation in
Piece *A*.   × 450.

[*Gregory & Whiteley.*

PLATE VI.
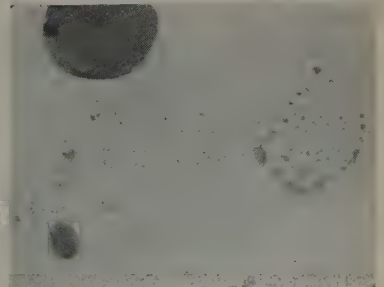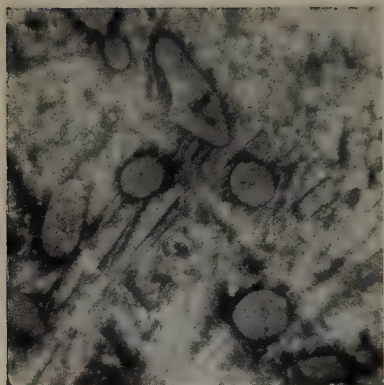
Fig. 27.—MnS in Translucent Ground-Mass of Globule. × 870.
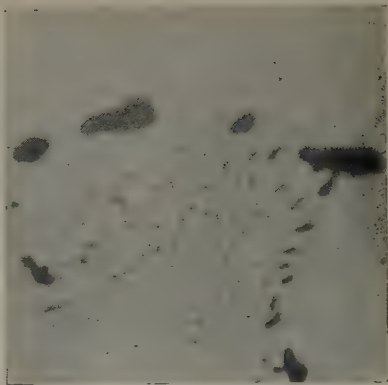
Fig. 28.—Secondary Sulphide Formation in Piece *A*. × 950.
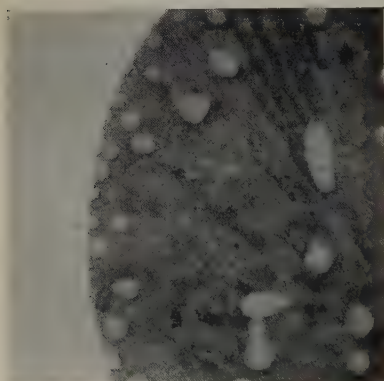
Fig. 29.—MnS and Ground-Mass in Globule. × 450.
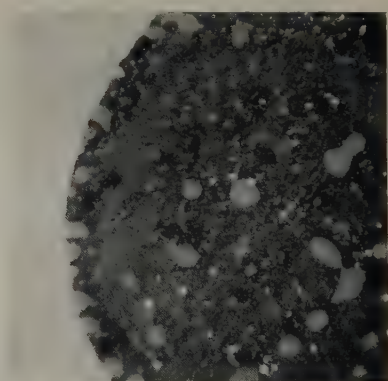
Fig. 30.—Globule after 86 hr. at 960° C. × 450.
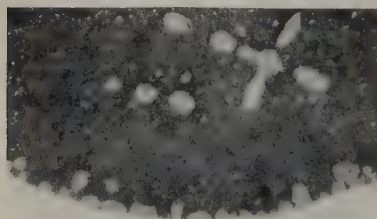
Fig. 31.—Globule Quenched from 1100° C. × 450.

Fig. 32.—Globule Quenched from 1300° C. × 450.

[*Gregory & Whiteley.*

PLATE VII.
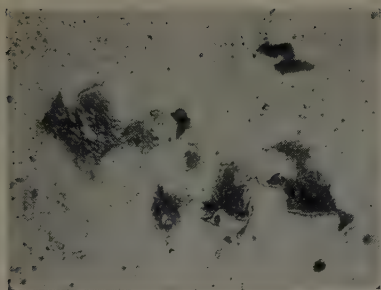
FIG. 33.—Coalescence of Pearlite in Welded Core.
× 450.
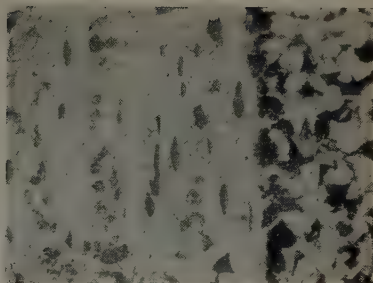
FIG. 34.—Weld Junction.   × 125.
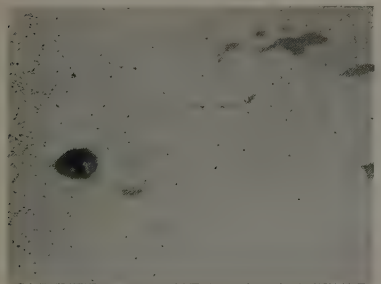
FIG. 35.—Inclusions in Welded Bath Sample.
× 950.
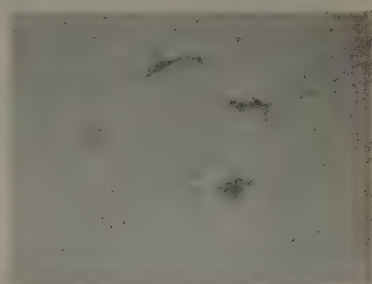
FIG. 36.—Sulphides in Welded Bath Sample,
2 hr. at 1220° C.   × 450.
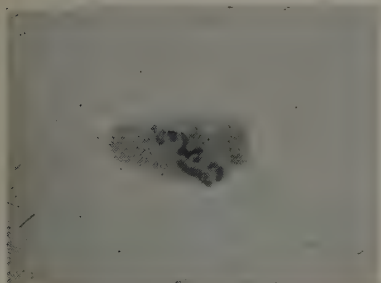
FIG. 37.—FeS–MnS Inclusion in Welded Bath
Sample, 2 hr. at 1220° C.   × 950.
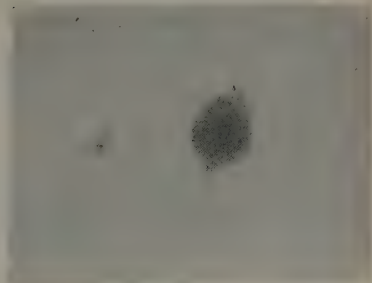
FIG. 38.—FeS–MnS Containing Silicate in Bath
Sample, 2 hr. at 1220° C.   × 950.
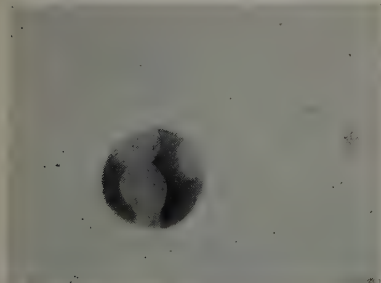
FIG. 39.—Globule with Preponderance of MnS.
× 450.
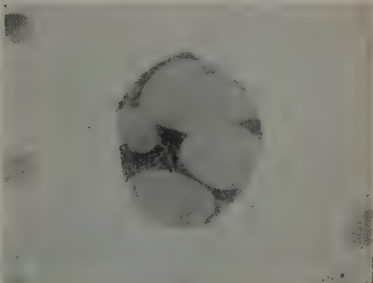
FIG. 40.—Globule with Preponderance of MnS.
× 450.

[*Gregory & Whiteley.*]

PLATE VIII.
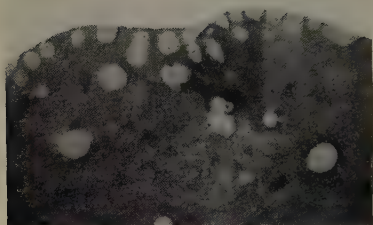
Fig. 41.—Globule with MnS, FeO and chromite. × 450.
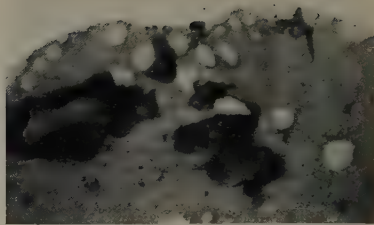
Fig. 42.—Same as Fig. 41 after etching in 2% HCl in alcohol. × 450.
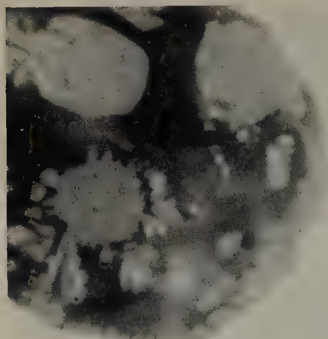
Fig. 43.—Globule Quenched from 1300° C. × 950.
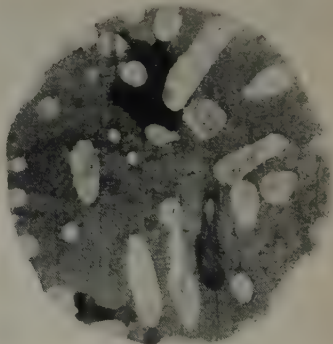
Fig. 44.—Globule with MnS, chromite and silicate. × 420.

Fig. 45.—MnS Dendrites in Globule Quenched from 1450° C. × 870.
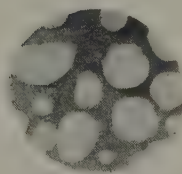
Fig. 46.—Typical Globule. × 420.

cooled steel, but, given sufficient FeO, it can readily be produced by cooling a specimen in air from about 1300° C.*   In the case of the FeO–FeS eutectic, cooling from 950° C. will serve.   Another characteristic of FeO very useful for identification is its easy solubility in very weak acids such as a 2% solution of hydrochloric acid in alcohol.   Immersion of the specimen for two or three minutes in this reagent will remove all small particles of the oxide and severely attack larger ones, whereas both FeS and MnS remain practically unaffected.

When the above test was applied to the class of inclusions under discussion, no FeO was found among them nor was oxide-sulphide eutectic to be seen in specimens air-cooled from 1300° C., and it was therefore concluded that MnS was the main constituent.   That these inclusions consisted entirely of MnS was, however, doubtful, for, as previously stated, only a comparatively few showed any translucency, the reflection then having a reddish colour.   Apparently the opacity of the majority was due to the presence of some substance in solid solution, but nevertheless the term MnS will be used to describe them.

The distribution of these particles in all three samples was fairly uniform, except that here and there a tendency to a network arrangement was noticeable.   Typical illustrations taken from samples Nos. 1 and 2 are given respectively in Figs. 15 and 16.   As a comparison will show, the inclusions in the steel near the skin of the ingot were smaller but more numerous than towards the centre. There was a similar difference between samples Nos. 1 and 3. Evidently, therefore, the sulphide inclusions increased in size as the rates of solidification and subsequent cooling became slower, a common feature in blow-hole-free ingots.   This growth, which may have been the result both of coalescence and of deposition from solution, will be further discussed later, since the subject seems to offer considerable scope for enquiry.   For example, the average dimensions of the MnS inclusions in a sample of any one class of steel may provide a useful indication of the size of ingot from which it was rolled or forged.

The next step in the investigation was to etch the specimens with a cupric reagent in order to ascertain whether any connection existed between their heterogeneity and the tendency to a network arrangement exhibited chiefly by the smaller MnS inclusions. For this purpose Le Chatelier and Dupuy's reagent was applied, and in each case a normal cored structure was revealed, with no outstanding heterogeneity.   MnS particles were still plainly visible, and it was found that the occasional partial network formations were situated outside the cores, while the largest of the sulphide inclusions always occurred within them.   Another three sections

* This temperature is needed because of the high melting point of the MnO–MnS eutectic, which, according to Andrew, Maddocks and Fowler,[1] is about 1280° C.

were then prepared and etched with the same reagent. This time two or three highly segregated areas were disclosed in both samples Nos. 2 and 3. A typical example is given under low magnification in Fig. 19. Although no complex globules were observed in these areas, they were manifestly richer in sulphide than the surrounding metal. Many of the inclusions were very large, light in colour and had a broken appearance, thus suggesting the presence of a considerable amount of FeS. On closer examination this was seen to be the case. Heavy inclusions of the brittle yellowish compound were found, and in addition there were numerous " duplex " particles composed of both FeS and MnS of the kind shown in Fig. 25. The formation of these mixed sulphide inclusions in steel has recently been discussed by the author so that here little need be said about them.[2] Their MnS constituent is invariably lighter in colour than ordinary MnS, owing, no doubt, to the fact that it holds a considerable amount of FeS in solid solution, as indicated in the equilibrium diagram of the system published by Shibata and Rigakushi.[3]

Having ascertained that FeS was present in quantity in the heavily segregated areas in the ingot, a lengthy examination was then made for this inclusion in the comparatively homogeneous parts, but, except for one mixture particle in sample No. 1, none was discovered. Seeing that the Mn/S ratio was low in the steel, the occurrence of FeS occasioned no surprise, for there was good reason to believe that, during solidification, this compound would form the bulk of the sulphide inclusions. Yet, since the manganese content exceeded by about 0.2% the amount required for combination with the sulphur, the whole of the FeS could have been converted to MnS, assuming, of course, that the diffusion of manganese into the segregate was sufficiently rapid. Anyhow, the quantity of FeS in these areas seemed altogether disproportionate, for elsewhere there was practically none. These considerations led to some experiments which will now be described.

First, in order to verify that FeS had been present in quantity in the liquidus-solidus range, two pieces of sample No. 2 were placed in a Meker furnace at 1400° C., as recorded by a disappearing-filament pyrometer. The temperature was then quickly raised until 1450° C. was reached, whereupon one piece (A) was air-cooled and the other (B) quenched in water. From their external appearances piece B seemed to have been in a more advanced state of fusion than piece A, and this was confirmed by the subsequent micro-examination, for, when sections were etched with the cupric reagent previously mentioned, the areas which had been liquefied were readily located. In piece B they formed a coarse network on which much less copper was deposited, as shown in Fig. 21, whereas in piece A these areas were small and separate, as shown in Fig. 22. Evidently, therefore, fusion had not proceeded as far in the latter piece as in the former. This interpretation was cor-

roborated by the fact that the large MnS inclusions originally
present had completely disappeared in piece B, while in piece A
about one-half still remained, all of which were found to be situated
in the parts where most copper was precipitated by the cupric
reagent. The inclusions in representative areas of these two
sections are shown respectively in Figs. 20 and 18, and a comparison
with the content of the original sample seen in Fig. 16 will illustrate
the extent of the change in each case. It was thus clear that two
stages in the process of fusion had been obtained, and, this having
been ascertained, an examination was then made for FeS in the
remelted zones, which were seen to be crowded with small sulphide
particles barely visible at the low magnification used for the above
illustrations. Under the oil-immersion lens, however, these in-
clusions were readily identified and were found to consist almost
entirely of either FeS, or a light coloured MnS, or else a mixture of
the two. This result thus fully confirmed the assumption that a
large proportion of the sulphur had existed as FeS in the ingot
during solidification.

The way in which the small sulphide particles were distributed
in the remelted areas of both pieces was suggestive of a eutectic
formation, the resemblance being particularly noticeable in the
quenched piece B, as can be seen in Fig. 23. A similar grouping
of MnS inclusions has been illustrated by Portevin and Castro,[4]
who describe it as "eutectiform." In piece A the particles in these
zones were of a somewhat larger size, although the manner of
deposition was the same, as the example in Fig. 24 will show. That
this mode of occurrence was actually eutectiferous was, however,
uncertain, and in the absence of definite evidence these groups will
be referred to as the primary formation. Now, as already stated,
many of the original MnS inclusions still remained in piece A and
it was consequently rather surprising to find another set of much
smaller sulphide groups in this piece yet more definitely eutecti-
ferous in character. Typical instances are given in Figs. 26 and 28.
These very distinctive particle arrangements will be termed the
secondary formation, since they were not present in the quenched
piece B, and must therefore have separated at a lower temperature
than the primary formation. This was also indicated by the fact
that, unlike the latter, they contained no FeS, the whole of the tiny
particles in each group consisting of translucent MnS.

From a careful survey of the relative positions of these two
formations, and from the difference between the sizes of their
particles, the impression was gained that they were the residues
of binary and ternary eutectics. If this interpretation is correct
the eutectic constituents certainly did not include iron, for accord-
ing to both Becker [5] and Miyazaki [6] the eutectic of the Fe–FeS
system contains about 85% of FeS and freezes at 985° C., whereas the
primary formation was already in piece B when it was quenched
from 1450° C. The temperature at which the secondary formation

appeared was also well above 1300° C., as was indicated in the experiments next to be described.

Since there was but little to be seen of the primary formation in the original samples and nothing of the secondary formation, it was inferred that both had been obliterated, even near the skin of the ingot, by the considerable coalescence which seemed to have occurred. An endeavour was therefore made to effect a similar change in pieces A and B. In the first attempt a section of each was heated in a closed silica tube of 15 c.c. capacity for 18 hr. at 950° C. The two were then examined and it was found, as was anticipated, that all visible FeS had vanished from both; only MnS was now present, but otherwise no alteration was to be seen, for, on comparing the specimens with the original pieces, their inclusions were not perceptibly larger in size. The same result was again obtained after the specimens had been heated for a further 72 hr. at this temperature.

In the next attempt the two sections were heated in a Silit-rod furnace for 1 hr. at 1250° C. and air-cooled afterwards, but once more no definite enlargement in the dimensions of the MnS inclusions could be detected. Particular attention was given in this test to the secondary formation in piece A on account of the very small size of its particles, yet, even there, little, if any, growth was apparent. Now, since the melting point of MnS is about 1600° C., particle growth can only take place in the solid steel by means of solution and diffusion. The above observations thus indicate that, as far as 1250° C., MnS is at most but slightly soluble in steel, a conclusion which was reached by Andrew and Binnie [7] some years ago.

The MnS inclusions having remained unaltered in size at 1250° C., a fourth and final heating was given at a still higher temperature. In this attempt the two pieces were inserted in the furnace at 1300° C. for 30 min., during which time the temperature was steadily raised to 1340° C.; the pieces were then withdrawn and air-cooled. Yet, even after this treatment, no change in the average size of the MnS inclusions was noticeable, except that the minute particles of the secondary formation were perhaps a little larger. Hence, it seemed clear that appreciable coalescence of MnS in the ingot must have ceased by the time the temperature had fallen to 1350° C. As to the growth of FeS inclusions and those containing some MnS, these tests afforded no information, since a complete conversion to MnS had occurred in the first heating at 950° C. FeS melts at 1190° C. and MnS at 1600° C., from which temperature the liquidus curve steadily falls until about 6% MnS is reached at 1170° C.— the eutectic point of the system—so that inclusions rich in FeS will remain in the liquid state for a considerable period after the metal has solidified; their coalescence would therefore be expected to continue to a temperature well below that at which the MnS becomes fixed in size. Some results obtained in the next set of

experiments fully supported this inference, but, before describing these, another observation already alluded to must be mentioned. In the final test at 1300–1340° C. a section of sample No. 3, in which there was a heavily segregated area, was also included in order to ascertain whether the secondary formation would appear in that range of temperature. A careful examination failed, however, to reveal any of these groups; FeS was still present in the segregate and had largely enveloped the grains, but otherwise there was no change in the arrangement of the sulphide particles.

In making the following tests the main purpose was to examine the diffusion of manganese in mild steel, since a reasonable explanation of the presence of FeS inclusions in the heavily segregated areas of samples Nos. 2 and 3 was that insufficient manganese had entered them as the ingot cooled down. Two effects due to manganese which seemed likely to be informative were employed, the first being its retarding action on the tendency of pearlite areas to coalesce at their margins. As is well known, the Ar_1 transformation in hypo-eutectoid steels takes place over a short range of temperature and, as was shown by the author [8] some years ago, while the transition continues, the borders of the pearlite grains already formed are apt to thicken by the transference of carbide from the areas of austenite still in the vicinity, the deposition becoming more rapid as the manganese content is lowered. With less than 0·40% the process can be so active as to change some pearlite areas in mild steel into massive carbide, even when the specimen is cooled in air. Coalescence in the ingot under discussion was found to be no exception to this rule, for, although the average manganese content was 1·023%, the greater part was in combination with the sulphur at 900° C., so that the actual amount in the austenite would almost certainly be not more than 0·30%; consequently the pearlite formed under a fairly rapid rate of cooling resembled that obtained in a low-manganese steel. For example, when a specimen of sample No. 1 and another of a steel containing carbon 0·10%, manganese 0·31%, sulphur 0·04% and phosphorus 0·02%, were cooled together from 1000° C. at a rate of 10° C. per min. through the critical range, the extent of the marginal coalescence in the two was about equal. Hence it was considered that this effect might be used as an indicator of the rate at which manganese diffused at different temperatures, and, in order to produce a gradient for the purpose, a welded sample was prepared as described below.

A 1¼-in. length was taken from a 1-in. dia. steel bar containing manganese 1·31%, carbon 0·12%, silicon 0·20%, sulphur 0·04% and phosphorus 0·026%, and the centre was hollowed to within ¼ in. of the bottom with a ⅜-in. drill. The cavity was then nearly filled by inserting a ⅜-in. dia. rod of sample No. 3 and, after a short steel plug had been hammered in, the end was made completely gas-tight with a thick covering of arc-deposited metal. Finally, to weld the two steels together, the cylinder was heated to about

1050° C., placed lengthwise on the anvil and forged down to a flat $\frac{1}{4}$-in. thick. A thorough weld was, of course, an essential require-ment for diffusion, and, in order to ensure that this had been obtained, three sections from different parts were examined before proceeding with the tests. The positions of the weld were readily seen, for on the core side the pearlite areas were largely divorced, while on the other side they were entirely sorbitic. The junctions appeared to be clean and perfectly sound, since crystallisation had everywhere taken place across them. This having been ascertained, a test for diffusion was made by heating one of the sections together with a piece of sample No. 3 for 5 hr. at 1120° C., after which they were cooled through the critical range at a rate of 10° C. per min. The structures of the pearlite areas in the two specimens were then compared, but no indication that manganese had passed into the core could be seen, notwithstanding the steep gradient across the weld. Even at places adjacent to the junctions, the pearlite had coalesced to the same extent as that in the original sample. Seem-ingly, therefore, little if any diffusion of manganese into the core had occurred, an inference which was subsequently verified by a determination of the manganese content, for after very carefully filing away the easily visible outer steel, an increase of only 0·03% was found.

Having obtained so small a result a second test was made, this time at about 1250° C., at which temperature a section of the welded piece was held for 3 hr.; it was then withdrawn, reheated to 1000° C. and cooled at the same rate as that employed in the previous test. Yet, even after this treatment, no diminution of the pearlite coalescence in the core could be detected, so that there was still no sign of any appreciable manganese diffusion. A typical example of the extent of the coalescence in both these tests is given in Fig. 33; in Fig. 34 the weld junction is shown, in order to illustrate the marked difference between the character of the pearlite areas on either side. The result at 1250° C. was also corroborated by an estimation of the manganese in the core, the increase being not more than 0·05%.

Thus the evidence indicated, at most, a very slow rate of manganese diffusion, so slow in fact that it was thought desirable to check this conclusion by means of an alternative method in which the conversion of FeS to MnS in solid steel was used as the indicator. This was, of course, a more direct attack on the problem under consideration, namely, the persistence of FeS in the segregate, and therefore no inference on diffusion could be drawn unless the above change occurred. Another welded piece was accordingly prepared in exactly the same manner as already described, except that the core now consisted of a rod cut from an acid steel bath sample of the following analysis : Carbon 0·12%, silicon 0·02%, sulphur 0·14%, phosphorus 0·12%, manganese 0·04% and alumin-ium nil. The inclusions in this sample were, as usual, very small

and required an oil-immersion lens for their proper examination. Sulphide particles were numerous and evenly distributed, and they existed entirely as FeS. The sample also contained some dark glassy inclusions of silica and silicate. A typical area in the welded piece with one of these particles and several FeS inclusions is shown in Fig. 35. Having ascertained that the weld was quite satisfactory, a section, together with a specimen of the bath sample, was heated for 2 hr. at 1000° C. This treatment resulted in the formation of some easily recognisable FeS–MnS mixture particles in both pieces, but, whereas not more than 4% was present in the bath-sample section, 12% was found in the core of the welded piece, these figures being arrived at by examining and counting several hundred sulphide inclusions in each of the specimens. Evidence of a slight manganese diffusion having thus been obtained, a second specimen of the welded piece was heated for 24 hr. at the same temperature. The increase in the number of mixture particles in the core was, however, not according to expectation, for only about 15% of the FeS inclusions showed any change. It should also be remarked that in both these tests, as in later ones, the proportion of mixture particles adjacent to the weld appeared to be no greater than that near the centre.

In order to accelerate the apparently slow rate of manganese diffusion, some further tests were then made at progressively higher temperatures, as indicated in Table IV., where the percentages of mixture inclusions produced are also recorded. It

TABLE IV.—*Percentages of Mixture Inclusions at Various Temperatures.*

Test No.	Temp. ° C.	Period of Heating.	FeS–MnS Mixture Particles. %.	Number of Sulphide Inclusions Visible at × 400.
1	1000	2 hr.	12	844
2	1000	24 hr.	15	680
3	1120	2 hr.	38	524
4	1220	2 hr.	51	404
5	1220 & 1300–1340	2 hr. 30 min.	40	...

will be seen that these particles became much more numerous as the temperature was raised. Yet no instance was encountered in which a complete conversion to MnS had been effected, for, although FeS was absent from some of the inclusions, these were all opaque and had a lighter colour than ordinary MnS. Nevertheless, it could be safely inferred that the movement of manganese had been facilitated by increasing the temperature. Judging by the results obtained in similar experiments on bath samples containing approximately 0·2% of manganese, about 0·15% had passed into

the core in test No. 4 at 1220° C.   That this estimate was not far out was evident on determining the manganese content of the interior portion of the core in test No. 5, where 0·16% was found, as against 0·04% to begin with.   Thus, diffusion had again been slow, although its amount was distinctly larger than in the pearlite coalescence tests.   In the present case, however, the gradient was somewhat steeper, and quite possibly the process had also been aided by the entrance of manganese into the sulphide inclusions.

A very noticeable feature in this series of tests was the gradual increase in size and consequent reduction in number of the sulphide particles; even after 2 hr. at 1000° C. they were for the most part definitely larger than in the original welded piece, and still more so after 24 hr., while at the three higher temperatures some of them became easily visible under a low-power objective.   In order to give some idea of this growth, particles seen at a magnification of 400 on either side of a line $\frac{3}{16}$ in. long, drawn down the core in four of the tests, were counted; the results are recorded in the fifth column of Table IV.   The drop there shown is pronounced, but, even so, it does not fully indicate the extent of the change, for many particles in tests Nos. 1 and 2 were still too small to be clearly discerned at the magnification used.   For that reason no attempt was made to count in the same way the yet more numerous particles in the core as forged, but from the numbers observable in one or two fields taken at random the figure was undoubtedly well over 1000.

An example of a mixed-sulphide inclusion formed in test No. 4 is given in Fig. 38, and another in Fig. 37, to which further reference will be made later.   Angularity, either partial or complete, was often seen, especially in tests Nos. 4 and 5, triangular FeS particles being frequently encountered.   At both temperatures the FeS inclusions would be in a liquid state, and, although this might not account for the idiomorphic crystals, it no doubt assisted the sulphide movement which had sometimes occurred along grain boundaries, as shown in Fig. 36.   The molten condition of most of the sulphide particles at 1340° C. may also explain the reduction in the proportion of mixture inclusions produced in that test, since the reaction FeS + Mn $\rightleftarrows$ MnS + Fe is reversible and proceeds towards the left with increasing temperature.   Indeed, the same tendency probably prevails in the solid state, for no mixture inclusions appeared in a section of the bath sample which was included in test No. 3, whereas in test No. 1, 4% was found as already stated.   Should that be the case, this reaction would tend to make the gradient less steep in the pearlite coalescence tests.   In passing, it may be remarked that the appreciable growth of the FeS inclusions which took place at 1000° C., a temperature well below their melting point, affords strong evidence of the solid solution of this compound in iron.   Recently the author described an experiment which indicated that at the above temperature at least 0·08% could be

dissolved.[9]   Some degree of solubility has also been demonstrated by Andrew and Binnie.[7]

Considering the results given by these two sets of diffusion tests, the inference that the persistence of FeS in the heavy segregate was due to a very slow movement of the manganese in the steel certainly seems plausible, especially when account is taken of the fact that not more than about 0·3% was available for diffusion into these exceptionally high-sulphur areas, which were, on the average, nearly as wide as the core in the welded samples. Whether this was the only factor concerned is, however, questionable, for in the above tests, the conversion of FeS to MnS seemed in places to be delayed, notwithstanding the increase of manganese in the vicinity. Fairly frequently a group of six or seven inclusions consisting entirely of FeS was seen in the specimens, and yet in closely adjacent groups a partial conversion to MnS was apparent in most of the component particles. This reluctance of FeS to change when the manganese content of the steel is low was observed by the author in a previous investigation.[2]

The occurrence of FeS in the segregate was of additional interest as being a direct and reliable indication of its presence in large amounts near the solidus point in this class of steel, and since this compound is known to cause red-shortness, severe cracking of the ingots might be expected. In America especially, the opinion is now freely expressed that the hot-working quality of steel deteriorates as the sulphur content rises. McCance[10] also maintains that sulphur is a fundamental cause of cracking and supports this view with statistical data which show that, as the sulphur content increases from 0·025% to 0·05%, the percentage of cracked ingots is more than doubled. He further states that the cracks appear within a few minutes of filling the mould or not at all. Yet very little trouble of that kind is experienced either in casting or in rolling the very high-sulphur ingots of the type under discussion. The reason is by no means obvious, but, from the effects observed in pieces A and B which were heated to within the liquidus-solidus range, a tentative explanation may be suggested. To make this clear, however, it will be as well first to consider how the cracking of ingots may be affected by the casting conditions, and in so doing use will be made of the following two published observations :

(1) Hultgren[11] some years ago demonstrated clearly that after-pouring disturbed the columnar crystallisation in ingots to within a short distance of the base, from which the reasonable inference may be drawn that, in top-filling, the stream from the nozzle can penetrate far down into the mould, even when it is almost full.

(2) Hall[12] has recently shown that, at temperatures just below the solidus, steels of different compositions are not only very weak but have little or no elongation. Hence, when the

ingot begins to solidify, the contraction stresses acting against the ferrostatic pressure may easily cause the early rupture noted by McCance. Of course, if a break occurs at the very outset of freezing, liquid metal may flow outwards and the rupture will be healed, but if it starts a little later, when a somewhat thicker skin has formed, the liquid within may not be reached and the crack will consequently tend to deepen as cooling proceeds.

Now, since in direct-teeming the stream seems to penetrate to a point near the bottom of the mould, it is to be expected that the whole of the metal, except perhaps that at the base, will remain molten, especially if very hot, until teeming is finished. Thus, freezing will commence almost simultaneously at all parts of the surface adjacent to the mould walls, with the result that contraction stresses, and therefore the tendency to cracking, will be at a maximum. When, on the other hand, the skin forms gradually from the base upwards, so that a distinct taper is produced, not only will the extent and suddenness of the overall contraction stresses be lessened, but also the lower part of the shell, being a little thicker and stronger, will be better able to withstand them. Incidentally, it may here be remarked that this condition is presumably brought about in the up-running method of casting, for, since the liquid steel then flows up the centre of the mould, the metal near the walls should be left relatively undisturbed. Consequently, freezing is more likely to begin in the lower half of the ingot first and even before the top half of the mould is filled. Much the same effect should occur also in tun-dishing, owing to the greatly reduced head of metal. The fact that both these methods of casting minimise cracking may thus be explained.

The above remarks are intended to relate chiefly to killed mild-to-medium carbon steel ingots of less than 15 tons in weight, for, given a sound skin about $\frac{1}{4}$ in. deep, subcutaneous blow-holes formed in unkilled steel tend to modify the contraction strains, apparently by acting as cushions. Now, as the liquidus-solidus range is widened, a similar effect seems to arise from the longer presence in the skin of liquid layers normal to the surface. At any rate, it is the author's experience that as the carbon content is raised above about 0.30%, the liability of direct-teemed solid ingots to cracking tends to diminish. In any one size of mould the change from the liquid to the completely solid state then takes place over a progressively lengthening period, with the result that the initial contraction compresses inwards the residual mother-liquor still between the crystallites and a rupture may thereby be avoided. This consideration leads to the explanation that the author had in mind of the fact that virtually solid top-filled low-carbon steel ingots very high in sulphur do not, as a rule, crack seriously as might be expected. It is suggested that large amounts

of FeS also widen the liquidus-solidus range, whereas comparatively small quantities merely tend to form the fine intergranular liquid films which are believed to give rise to red-shortness.

Having dealt with the sulphides, attention can now be turned to the second type of inclusion found in the samples. As already stated, this consisted of globules, complex in structure, sometimes very large and by far the most numerous in sample No. 2. Their ground-mass was composed of a brittle, dark, translucent mixture of fine texture in which several very obvious rounded, opaque, dove-grey inclusions were usually embedded. Only a few instances were encountered where the ground-mass comprised the whole sectioned area of the globule. That these dove-grey particles, although opaque, were essentially MnS there could be no doubt, for in sample No. 2 composite inclusions were frequently seen with but small proportions of the dark glassy substance, while the rest was unquestionably MnS. In fact, starting with an opaque MnS particle, a series could easily have been selected showing a gradual increase of the ground-mass material until it constituted the whole inclusion. Two examples showing a preponderance of MnS are given in Figs. 39 and 40. Again, all the dove-grey particles when heat-tinted had exactly the same light-blue colour as the outside MnS inclusions. Moreover, this component occasionally occurred in the form of a dendrite—a characteristic of MnS when it crystallises in material of comparatively low freezing point. An instance taken from the quenched piece B is shown in Fig. 45. Thus these, and other observations to be given later, all led to the same conclusion, namely, that the dove-grey particles within the globules were MnS.

The ground-mass when viewed under a $\frac{1}{6}$-in. objective seemed to be eutectiferous, the mixture consisting for the most part of two substances, one of which was dark, glassy and often in parallel layers, while the other was distributed as a yellowish network of extremely fine particles. A representative example is given in Fig. 29, in which the dark layers are apparent, with lines of the barely visible fine particles between them. Unfortunately, no better resolution was attainable, for under the oil-immersion lens the constituents became less distinct, owing to a general translucency, as can be seen from the illustration in Fig. 27. Besides MnS particles of varying size, two other darker inclusions were occasionally embedded in the ground-mass. Both were opaque, or nearly so, and one was invariably idiomorphic, while the other was irregular in shape. In Fig. 41 the two are shown in juxtaposition, and it will be noticed that both contain some MnS particles. Thus, from two to at least five types of inclusion were observed in these complex globules, and for further reference it will be convenient to number them as follows :

1.—Large and also very small MnS inclusions.
2.—A dark glassy substance in the ground-mass itself.

3.—Extremely fine particles with a yellowish tint distributed in the ground-mass as a network or in lines.

4.—Very dark idiomorphic crystals.

5.—An opaque material resembling MnS in colour but distinctly darker.

As already stated, the No. 1 class was undoubtedly MnS. The others had still to be identified, and, taking into account the fact that no deoxidisers except ferro-manganese were used in making the steel and also that it contained on the average at least 0·03% of oxygen, the following tentative conclusions were reached as a result of the careful inspection of the globules. Type No. 2 was in all probability a silicate. The yellowish tint which the extremely finely-divided No. 3 gave to the ground-mass suggested FeS. Type No. 4 strongly resembled chromite both in colour and in shape, while No. 5, from its appearance, was judged to be FeO. Having formed these opinions, an endeavour was then made to verify them by means of the tests described below. To begin with, the specimen was heat-tinted to a golden brown and examined; it was then repolished and successively immersed for 2–3 min. in the following reagents :

(a) A 2% solution of hydrochloric acid in alcohol.
(b) A 2% solution of sulphuric acid in water.
(c) Hydrofluoric acid.

The effects of these treatments on the five types of inclusions are recorded in Table V. It will be seen that they were distinctly favourable to the views expressed above and again stated in the second column.

TABLE V.—*Inclusion Types.*

Inclusion Type No.	Tentative Opinion on its Nature.	Heat-Tinted Colour.	Reaction to—		
			2% HCl in Alcohol.	2% H_2SO_4 in Water.	HF.
1	MnS.	Light-blue.	Insoluble.	Completely soluble.	...
2	Silicate.	Dark-grey, no definite change.	Nearly insoluble.	Nearly insoluble.	Strongly attacked.
3	FeS.	Indefinite.	Probably insoluble.	Not visible.	...
4	Chromite.	Very dark, no change.	Insoluble.	Insoluble.	Unattacked.
5	FeO with MnO.	Darker blue than No. 1.	Completely soluble.	...	...

That the No. 5 type of inclusion was either FeO, MnO or a mixture of the two, could now be regarded as proved, for no other similar substance commonly present in steel is so readily dissolved by very weak acids. Some idea of the extent of the attack by reagent (a)

on this inclusion can be had from a comparison of Figs. 41 and 42, which show the same area before and after a 3-min. immersion followed by a very light polish on the cloth. Besides the black cavities in Fig. 42, where the No. 5 inclusion had been, a small change in the number of MnS particles will also be noticed; it was inferred from this and other indications that the ground-mass itself was not entirely insoluble. Considering the fairly high oxygen content of the steel, some surprise was felt that so little FeO was observable, but, except within the complex globules, none was discovered in any of the samples, nor was any oxide-sulphide eutectic found in the piece A after it had been air-cooled from 1450° C. Presumably in the case of samples Nos. 1 and 3 most of the oxygen must have been in solution either in the iron or in their abundant MnS inclusions, since they contained but very few complex globules; indeed, the general opacity of the MnS might thus be explained.

Again, there was nothing in the behaviour of the idiomorphic No. 4 inclusion in the above tests to negative the assumption made as to its nature. Like chromite, this substance was completely insoluble in all three acids, as was evident from the fact that in several instances a crystal could still be seen standing intact in the deep cavity produced by the hydrofluoric-acid attack on the ground-mass. Small amounts of chromium are invariably present in steel, and the ingot under discussion had 0·036%. Consequently, with increasing oxidation, as the carbon content of the bath was reduced below about 0·10%, a little chromic oxide may have been formed, as sometimes happens, especially when the iron-oxide content of the slag is high. That the steel actually contained chromic oxide was proved on receipt of a further portion of sample No. 2. A 65-g. piece was dissolved in nitric acid (sp. gr. 1·2); the solution was then treated with potassium permanganate, cleared with ferrous sulphate, and the insoluble residue obtained. It weighed 0·025 g. and contained 0·0011 g. of chromium, equivalent to 9·1% of chromite. As in the case of the FeO inclusions, the No. 4 idiomorphic crystals were only found within the complex globules, but whether the material was a component of the system or was merely an entrapped addition could not be ascertained; all that can be said is that, unlike MnS and FeO, it never occurred as very small particles in the ground-mass.

With regard to the glassy No. 2 inclusions, the rapidity with which hydrofluoric acid attacked them left little doubt that they were, as surmised, a silicate, notwithstanding that the steel contained less than 0·01% of silicon. This substance could, in fact, be regarded as in all probability either fayalite or rhodonite, for, in view of the frequent presence of the base FeO in the globules, silicates holding a higher proportion of silica would scarcely be formed.

As to inclusion type No. 3, the tests gave no definite information on account of the difficulty in observing the effects on the extremely fine particles of which it was composed. The possibility of coalescing

these particles was therefore considered, and, as a first attempt, a specimen was heated in a closed silica tube for 24 hr. at 960° C. After this treatment, however, no distinct increase in size was detected, but after a second heating for 62 hr. at the same temperature there was a noticeable change. The No. 3 inclusions had been replaced by many definitely larger particles, which strongly resembled MnS both before and after heat-tinting, and also in their behaviour in reagents (a) and (b). These particles are to be seen in Fig. 30, where the alteration in the general colour of the globules is also evident in the darker shade of the ground-mass as against that of the original shown in Fig. 29, the tone of the MnS inclusions being taken as the standard of comparison. In addition to these changes another was manifest. As shown in Fig. 30, the ground-mass of the globules now contained a number of the white particles, and it was at first thought that these new inclusions might be a carbide, but subsequent tests proved them to be ferrite. They remained unstained after immersion for 2 hr. in cold sodium picrate, and, when the specimen was heat-tinted, were of the same colour as the adjacent metal. Whether this ferrite had been precipitated during the prolonged heating or was originally present in extremely fine division, was uncertain, although deposition seemed the more likely, since the particles vanished again on heating the section to 1300° C.

Reverting to the other change, the disappearance of the No. 3 type particles from the ground-mass with the increase in the small MnS inclusions strongly suggested that the former were in fact FeS, and that a conversion to MnS had taken place by their interaction with the manganese in the surrounding silicate. The association of sulphides and silicates of iron and manganese is a matter of common observation. A striking example of the two coming together in solid steel was encountered in the manganese diffusion tests made on the acid bath sample (Table IV.). In the cast condition this sample contained, besides the numerous FeS particles, a lesser quantity of dark glassy siliceous inclusions, and usually the two varieties occurred separately, as shown in Fig. 35. Yet in the tests in which specimens were heated at 1250° and 1340° C., practically the whole of the siliceous material was absorbed by the FeS, with the result that many composite inclusions were formed of the kind seen in Fig. 37.

The evidence so far available was, therefore, not unfavourable to the view that the translucent ground-mass of the globules consisted for the most part of an intimate mixture of fayalite and/or rhodonite, with FeS and some MnS. Having arrived at this tentative conclusion, further corroboration was obtained from a study of a paper by Andrew, Maddocks and Fowler [1] in which these authors record a thermal and microscopic investigation of the MnS–fayalite and the MnS–rhodonite systems. They found the two to be very similar, both having a simple eutectiferous form

with a limited solubility at either end.   The thermal data indicate that the eutectic of the MnS–fayalite system melts at about 1050° C.; in the other system the melting point is near 1250° C., and both eutectics contain about 10% of MnS.   While no illustrations are given of the MnS–fayalite microstructures, several of the MnS–rhodonite are presented, including the eutectic, and on examining this carefully it was seen to have a close resemblance to the ground-mass of the complex globules shown, for example, in Fig. 29.

A further experiment was thus suggested.   It seemed worth while to quench the specimen of sample No. 2, which had been heated for 86 hr. at 960° C., and another of the untreated sample from a temperature just above the melting point of the MnS–fayalite eutectic and compare the effects produced in the globules. This was accordingly done, a 7-min. heating at 1100° C. being given in a non-scaling atmosphere, whereupon the tube was opened and the specimens were at once dropped into water.   On examining the specimen from the original sample a definite change in the globules was seen, in that the fine particles of the No. 3 inclusion type had disappeared from the ground-mass and only a relatively few small MnS inclusions were left, as shown in Fig. 31.   The ground-mass itself seemed to have been in a viscous condition, for it was now a dark, but not quite uniform, glass, as a comparison with Fig. 29 will indicate.   In the other section which had been previously heated at 960° C. no alteration could be detected, the structures of two or three of the globules being exactly similar to that shown in Fig. 30.   This specimen was, therefore, given another short heating at 1300° C., a temperature immediately above the eutectic point of the MnS–rhodonite system, and again quenched.   At this temperature a marked alteration in the globules occurred, to the extent that some were structureless and evenly glassy, as shown in Fig. 32. Moreover, no ferrite particles were now visible, and in some instances the large MnS inclusions seemed to have been breaking up as though in process of solution.   An example is given in Fig. 43, in which the translucency of the small detached MnS particles at the sides of the main inclusions will be noticed.   In one or two of the globules only these minute particles remained, while, on the other hand, the MnS constituent in others seemed to have increased.

Thus, to sum up the evidence obtained from these various tests, the indications were that the ground-mass was eutectiferous and belonged to the system MnS–FeS–fayalite–rhodonite with the occasional addition of FeO.   In further support of this conclusion one other observation should be mentioned.   As a rule the larger inclusions within the globules were MnS, with sometimes FeO and/or the No. 4 type of inclusion, but once or twice a glassy silicate was found.   An illustration is given in Fig. 44, where, in addition to one of the idiomorphic crystals, two dark particles showing an internal reflection are to be seen.

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DISCUSSION.

This paper was presented for discussion at a Joint Meeting of the Institute with the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association held at the Royal Victoria Station Hotel, Sheffield, on Saturday, October 4th, 1941, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of the Institute).

Mr. N. H. Bacon (Messrs. Steel, Peech and Tozer, Sheffield) said he was particularly interested in the fact, which was quite unexpected, that the high-sulphur steel rolled in such a good manner without cracking. One would naturally expect high-sulphur steel to crack, for the reasons stated by Mr. Whiteley. It had been found by McCance that high-sulphur steels did crack more than low-sulphur steels. His firm, with the ordinary run of steels, had found some years ago that as the sulphur increased from 0·03 to 0·05 or 0·06% cracking increased, and it was therefore all the more surprising to read the result found by Dr. Gregory. A few days ago they actually ran a cast with 0·35% of sulphur—not to imitate Park Gate but purely by accident—and that cast rolled quite well.

Another interesting point was that recently they had been adding 0·2–0·3% of lead to sulphur steel, and there again they had had a great surprise. They found that a 0·2% sulphur steel with 0·2% of lead cracked very much less than a 0·2% sulphur steel without lead. It seemed to him that the lead had a similar effect to an increase in sulphur.

Dr. W. R. Maddocks (University of Sheffield) said that the paper dealt to a large extent with the segregation that had occurred in the ingot. One was impressed by the unsymmetrical segregation in what might be termed the " heat centre " of the ingot. It was apparent that the rate of growth of the columnar crystals was associated with the degree of segregation that occurred in the body of the ingot.

The authors made the statement : " If the elements which normally tend to segregate are nearly absent, the segregation must be reduced to an absolute minimum." For pure materials this must be true, but in the case of steels the complicated peritectic reactions taking place at, or near, the liquidus temperature might cause segregation of elements that were present in very small quantities.

If the ingots examined in the Reports of the Committee on the Heterogeneity of Steel Ingots were studied, and considering solid ingots only, there seemed to be some correlation between the carbon content and the degree of segregation generally. In ingots containing less than 0·3% of carbon the amount of segregation was small, though obvious, when compared with ingots containing more than 0·3% of carbon. With less than 0·3% of carbon the segregation of that element would be up to 0·45% in the top centre of the ingot,

and with ingots containing 0·4% of carbon, the carbon segregated
to something of the order of 0·7–0·9%.   The other elements, sulphur
and phosphorus, segregated to a similar degree.   One wondered
whether the authors were, therefore, justified in saying that " in
a steel containing, say, an average of 0·05% of sulphur this degree
of segregation would result in areas containing 0·054% and 0·046%
of the element, an indicated degree of segregation which is often
much less than that found in practice."   The authors were dealing
with an ingot which contained a very small amount of carbon, and
he (Dr. Maddocks) thought that before a parallel could be drawn
between degrees of segregation in other ingots, it would be desirable
to make the comparison on ingots containing the same amounts
of carbon.

In the majority of ingots examined by the Heterogeneity Com-
mittee a certain amount of inverse segregation occurred in positions
corresponding to the heat centres of the ingots.   In such cases the
ingots were purer at the inside than at the outside positions.   It
was interesting to note that in the ingot examined by the authors,
the oxygen and hydrogen contents at those particular positions
were higher in the inside than in the outside areas of that zone.

There was another ingot in the Heterogeneity Reports—No. 29—
which was also a sulphur free-cutting steel ingot.   The sulphur
had segregated to an enormous amount, from 0·115% to 0·295%.
He would like to ask the authors' opinion of the reason for the great
difference in the degree of segregation in the two ingots.

Professor J. H. ANDREW (University of Sheffield) said that one
thing which struck him most forcibly was that sulphur appeared
to be an excellent deoxidising agent.   Dr. Trent and himself had
proposed a theory some years ago in which they attributed the
segregation in an ordinary ingot to the CO developed by the re-
action between FeO and carbon.   When they added sulphur they
stopped that reaction altogether.   His opinion was that in a high-
sulphur steel, instead of getting the oxygen in a gaseous combina-
tion, it was used up to form slag, and it was for that reason, there-
fore, that they obtained an absence of normal segregation in high-
sulphur steel.   He was therefore rather pleased with this paper,
because it did appear to give further evidence that the idea of
the FeO + C reaction was responsible for segregation might be
correct.

With respect to Mr. Whiteley's contribution, one always
associated him with most marvellous metallographic work, and it
did appear to the speaker very evident that much of the physico-
chemical work that many were now undertaking with regard to
steel might be rather misleading.   Mr. Whiteley had shown that the
inclusions might contain anything up to six elements.   Was it of
great use, therefore, to consider binary systems, or even ternary
systems, of slags and apply the data to steel ingots ?   Mr. Whiteley

had shown that, depending upon the particular area of an ingot, inclusions might be binary, ternary, quaternary or have five or six components, and he had demonstrated very clearly that the particular form of inclusion obtained within the steel would depend upon the contact between the different components in different areas in that steel. A large amount of the highly scientific work undertaken with regard to ingot structure might be not nearly so useful as the work that Mr. Whiteley was doing.

In a few words, Dr. Gregory had shown, by making this steel, that sulphur was an extraordinarily good deoxidising agent, and Mr. Whiteley had brought to light many new ideas with regard to inclusions in steel.

Dr. W. H. HATFIELD, F.R.S. (Brown-Firth Research Laboratories, Sheffield), said that his colleagues and himself were carrying out a major research at the present time, and had been doing so for some few years, on the effect of varying amounts of work on various steels, starting with carbon steel and working through the hardened and tempered alloy steels. They were trying to obtain a really reliable picture of the effect of varying amounts of hot-work, *i.e.*, whether the reduction was twice, or four times, or eight times, or 100 times, as was sometimes the case. What was the effect of hot-work on the mechanical properties? Of course, a study of that kind was not complete if they simply determined the mechanical properties in the longitudinal direction; they must also do transverse tests.

Dr. Gregory asked him to assist in some small measure in the examination of the ingot described in the paper, and, having done that work, he could not resist the temptation to hammer the half-ingot down into a big bloom, take tests, and then hammer it further and further, putting varying degrees of work upon the ingot, and then see what were the mechanical properties of an ingot containing 0·5% of sulphur when tested in the longitudinal and transverse directions after varying amounts of work. The results obtained were shown in Table A.

They had there, he suggested, a most remarkable contribution to the knowledge of the mechanical properties of steel. They had all been taught since their young days that inclusions in steel were detrimental, and of course they knew that that was so—at least, they still believed it—but here they had this ingot in which there was 0·5% of sulphur, resulting in an abnormal amount of sulphides, oxides, silicates, oxides of chromium and so on, and yet this material responded in a remarkable degree similarly to other steels, except for the last test, which he simply put down to misadventure in that the particular test-piece happened to coincide with probably rather an accentuated segregate. That raised the whole question as to why, when Dr. Gregory put 0·5% of sulphur in his steel, the tensile strength and the ductility were maintained. The figures he had

TABLE A.—*Effect of Hot-Work on the Mechanical Properties of a 0.5% Sulphur Steel.*

Forging Reduction.	Yield Point. Tons per sq.in.	Max. Stress. Tons per sq. in.	Elongation. %.	Reduction of Area. %.	Impact Value. Ft.lb.
Outside of Ingot.					
Tests in Longitudinal Direction.					
As cast	15·60	23·60	30·50	34·00	23, 22, 19
2 : 1	15·90	23·80	37·50	54·00	35, 36, 36
4 : 1	16·20	23·80	36·00	57·00	39, 39, 39
8 : 1	18·00	24·20	37·00	57·00	39, 37, 38
16 : 1	17·00	24·20	36·00	57·00	45, 41, 39
Tests in Transverse Direction.					
As cast	12·80	23·00	29·50	36·50	15, 16, 19
2 : 1	16·40	23·80	34·50	43·50	24, 20, 26
4 : 1	16·80	23·80	24·00	22·50	19, 21, 20
8 : 1	16·80	23·60	31·00	41·50	20, 19, 21
16 : 1	17·00	23·60	28·00	33·00	19, 18, 18
Centre of Ingot.					
Tests in Longitudinal Direction.					
As cast	12·80	22·50	30·00	35·00	22, 23, 22
2 : 1	15·80	23·80	34·00	53·00	44, 42, 38
4 : 1	16·80	23·80	36·00	56·00	49, 56, 54
8 : 1	17·00	23·90	38·00	57·00	50, 53, 55
16 : 1	17·20	23·80	37·50	58·50	49, 53, 52
Tests in Transverse Direction.					
As cast	11·60	21·60	17·50	22·50	21, 19, 19
2 : 1	15·80	23·20	24·50	24·50	22, 23, 20
4 : 1	16·00	22·60	15·00	18·00	16, 20, 17
8 : 1	16·80	21·60	14·00	19·00	16, 20, 19
16 : 1	12·40	13·20	3·00	11·00	18, 15, 20

given were comparable, having in mind tensile strength, with any other kind of steel.

Dr. GREGORY said that Dr. Hatfield's figures were extremely interesting, and he thought everyone would agree that they were perhaps much better than one would have anticipated from their earlier teaching. He exhibited specimens of the steel in various forms, and said he was not surprised at the uniformity of the mechanical tests.

Mr. WHITELEY also said the results were most interesting. He pointed out that at the outer zone of the ingot there were very few of the complex inclusions, but in the centre part a large number were present. Now, where the complex inclusions were almost absent there was very little, if any, fall in the transverse elongation,

but there was a progressive fall in the centre, where these inclusions were numerous. He suggested to Dr. Hatfield that that might be the reason of the difference between his two sets of results.

Mr. H. BULL (Messrs. Brown Bayley's Steel Works, Ltd., Sheffield) said that there was an old belief, which Dr. Hatfield had seemed to explode, that the sulphides and other non-metallics were really the fundamental thing causing the difference in transverse tests between one steel and another of the same type. They were not, of course. It was true of any steel that one could not, by looking at the chemical composition, judge what transverse impacts in particular were likely to be obtained from it, whether it was a nickel-chromium steel in a hardened and tempered condition or a dead soft steel. He thought Dr. Gregory had shown that he had made a very good steel of its type, and it had very good cross properties. In his own experience he had had steels with sulphur contents of the order of 0.020% which had given poor impact tests in the cross direction, and he was sure that that must be the experience of all those who were habitually producing such things as were tested in the transverse direction. That only led him to say that in his own work on this subject he was not in the habit of looking at one ingot to decide what the fundamental effects of certain things were. He thought Dr. Gregory might not be satisfied about these matters until he had tested more ingots. He congratulated Dr. Gregory on his results ; did he think he would get similar results if he tested half-a-dozen ingots of the same composition from different casts ? If sulphur was acting as a deoxidiser it might help.

Mr. W. W. STEVENSON (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) said that he did not propose to criticise the details of Mr. Whiteley's contribution, but there seemed to be a lot of very essential data missing from the paper. If they looked at Fig. 2, the only element that segregated to any great extent was oxygen. There was nearly four times as much in the centre of the ingot as on the outside edge, and similarly about four times as much at the bottom as at the top. Following that, Dr. Gregory stated, on p. 14 P, " Unfortunately, at the moment, there appears to be no absolutely reliable method of analysing the inclusions." As a member of the Oxygen Sub-Committee he (Mr. Stevenson) suggested that they were advanced enough to give some indication as to the constitution of those inclusions.

Dr. HATFIELD asked could he take them out of the steel ?

Mr. STEVENSON replied that by the alcoholic iodine method one could isolate them.

Dr. HATFIELD said he did not think he could get the sulphides.

Mr. STEVENSON replied that he was not discussing sulphides. He was referring to segregation of oxides. By fractional vacuum fusion one could also indicate the form of occurrence of the oxides. It seemed a great pity that they had not got the cast history, which would tell them the oxygen from charging to tapping, so that they could follow what happened during the heat. The first samples that were analysed were the pit tests and the test ingots, and none of these samples had been examined for oxygen contents. Had they had the cast history, or if some attack on the inclusions had been made by either of the two methods that he had suggested, he thought they would perhaps be nearer to providing a little more confirmation for Professor Andrew's theory of sulphur deoxidation. If samples were available, he suggested that some attempt should be made to obtain the constitution of the oxygen at different parts of this ingot, on which so much work had been done.

Dr. M. L. BECKER (Messrs. David Brown & Sons (Hudd.), Ltd., Huddersfield) asked if Dr. Gregory could say how much aluminium was added to the steel. He supposed that in basic steel of this type some aluminium would be used, and he felt that this might have some influence on the very interesting results recorded. If, as was stated in the paper, the metal was fairly highly oxidised at the time of tapping, the addition of aluminium would presumably cause a sudden reaction and might have some influence upon the subsequent segregation of the sulphides. In this connection, he would also like to know the inherent grain size of the steel.

With regard to Dr. Hatfield's figures (Table A), it certainly was remarkable that such high values were obtained in the transverse direction, and this showed that a high sulphur content was not necessarily harmful as far as mechanical properties were concerned, provided that the form and distribution of the sulphide segregates were under control. Such relatively high transverse-test values seemed to be unusual even in high-quality alloy steels, presumably containing smaller quantities of inclusions of a different type.

Dr. HATFIELD, referring to Mr. Stevenson's remarks, said that, as was common with all ingots examined by the Heterogeneity Committee, pieces of the ingot under discussion were still in existence, and any line of attack such as Mr. Stevenson had suggested could be dealt with. If Mr. Stevenson felt that he could take a piece of the steel from different portions of the ingot and really give a full Ruskinian picture of the composition of the inclusions, then he should have the opportunity of doing so.

With regard to Dr. Becker's remarks, he (Dr. Hatfield) knew quite well that this ingot was typical of a commercial product which was being produced by the Park Gate Co. in thousands of tons. In carrying out his investigations he merely added this ingot to his list in cynical amusement, thinking that he would have

the extreme effect of the inclusions, and it was to his astonishment that the non-metallic matter, in the form which had been put to them that day, did not have the effect that he expected.

Mr. WHITELEY said there was one question that he would like to put to Dr. Gregory. Had he rolled any of these ingots into ¼-in. plates, say, and tested the transverse bends of those plates?

Dr. HATFIELD remarked that that was not Mr. Whiteley's point. The point was what were the properties of a test-piece cut through a ½-in. plate. His own test figures related to the physical properties disclosed in a through test.

Mr. WHITELEY agreed, but commented that one must not run away with the idea that inclusions did not matter. He wanted to find out whether a ¼-in. plate rolled from one of these ingots would give a bad transverse test. He thought it would.

Dr. A. H. JAY (The United Steel Companies, Ltd., Stocksbridge, near Sheffield), referring to the constitution of the inclusions, said that it had been found possible to separate sulphides from a bar of a high-sulphur steel (sulphur 0·25%, manganese 1·0%), collect them as a powder and analyse them by the X-ray powder method. In the samples examined the sulphide was MnS (cubic symmetry) and no FeS was found.

Dr. HATFIELD asked, when he separated the sulphides, what proportion did he manage to separate?

Dr. JAY replied that these were preliminary tests, and he had made no measurement of the percentage examined to that in the steel.

Dr. HATFIELD commented that probably he had a big loss.

Dr. JAY, asked by Mr. Whiteley how this was done, said that the separation was made by the use of a method described by Dr. U. R. Evans,[1] in which he (Dr. Evans) separated very thin oxide films from metals by dissolving the metal away. He (Dr. Jay), believing that a method which did not destroy these oxide films could be tried for the separation of sulphides, had made the tests referred to above.

Dr. HATFIELD said that, within the measure of what Dr. Jay had achieved, what he had told them was of very great interest. But anyone who had worked on the attempt to separate constituents from the matrix must know that it was a very difficult task,

[1] Fifth Report of the Corrosion Committee, p. 225, *Iron and Steel Institute*, 1938, *Special Report No. 21*.

and, while it was reasonable for Dr. Evans to talk about leaving oxides and sulphides *in situ*, he should question it very much as a matter of fact. However, Mr. Stevenson had volunteered to implement this matter. They would take care to see that he had pieces taken from different portions of the ingot, and they would look forward to his telling them what he found.

Mr. STEVENSON, in reply to Dr. Hatfield's suggestion that samples be made available, said, on behalf of Dr. Swinden, that they would be delighted to examine a few samples and report upon them. In regard to the separation of sulphides, had the war been delayed a few months longer, it was likely that Professor Skapski, of Cracow, would have told them how to separate the sulphides. They had seen privately a lot of his very valuable work. But he (the speaker) was not worried so much about the sulphides. He was mainly concerned about the segregation of oxygen, and its form of occurrence.

Mr. T. F. RUSSELL (English Steel Corporation, Ltd., Sheffield) said he would like to comment on the sulphur print of the ingot and ask Dr. Gregory a question which had a direct bearing on his (Mr. Russell's) paper.[1] Dr. Gregory had stated in the last paragraph of his Section " a Member of the Committee has drawn attention to the eccentricity of the columnar zone shown in the macro-print (Fig. 4). This eccentricity is readily explained by the position of the ingot relative to the other ingots in the casting pit." Could Dr. Gregory tell them *with absolute certainty* what was the relative position of the ingot in the casting pit and how this caused eccentricity of the columnar zone. He took it that Dr. Gregory would say that one side of the mould had been hotter than the other, and that caused the difference in the depths of the columnar zones and a difference in the times for solidification near to the hotter and colder sides. It would, however, be of interest to know exactly whether the deep columnar zone was at the hot or the cold face of the mould and—assuming that there was a difference in the rates of solidification near to these faces—why the central segregated portion was not also off-centre. The importance of this question would be the more obvious to Dr. Gregory and Mr. Whiteley when they had considered the experimental results of Granat and Bezdenezhnykh [2] referred to in his (Mr. Russell's) paper. He had very little doubt that the lop-sided segregation was caused by one side cooling faster than the other.

[1] "The Thermal Relations between Ingot and Mould," *Journal of the Iron and Steel Institute*, 1941, No. I., p. 163 P. This paper was also presented at the Joint Meeting in Sheffield; the discussion on it will be found on p. 289 P of the present volume.

[2] I. Ya. Granat and A. A. Bezdenezhnykh, *Metallurg*, 1938, No. 10, p. 19 : *Foundry Trade Journal*, 1939, vol. 61, No. 16, p. 335.
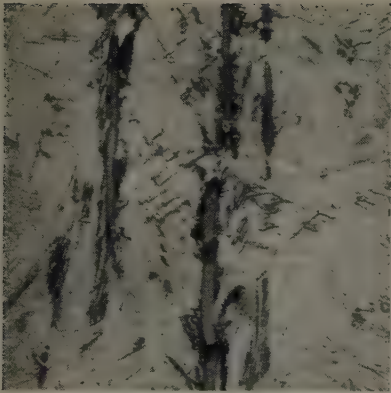
FIG. A.—Cool End of Bar. Sulphides un-
affected, normal elongated condition.
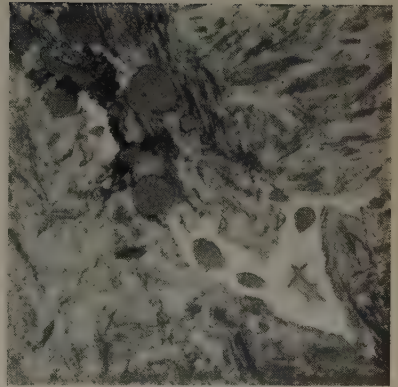
FIG. B.—Towards Hot End of Bar. Sulphides
spheroidised.

FIGS. A to C.—Rolled Steel Bar (carbon 0·4%, manganese about 1·5%, sulphur 0·11%), one end heated
to melting point.
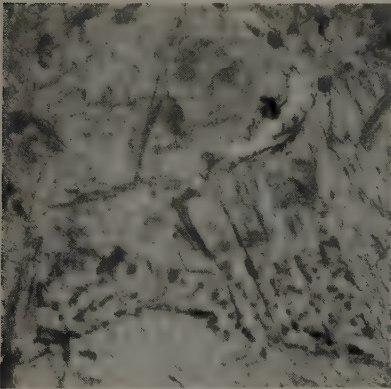
FIG. C.—Near Fused End of Bar. Sulphides in
eutectic form.
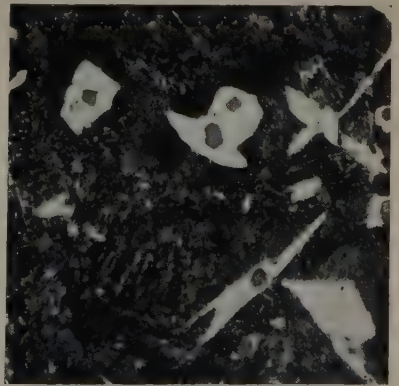
FIG. D.—Ingot Overheated in Soaking Pit.
Idiomorphic sulphides; unattacked by 5%
alcoholic hydrochloric acid, removed by 10%
aqueous chromic acid solution.

FIGS. A to D.—Direction of Rolling in Plane of Paper. Picral etch. × 1000 (reduced to four-fifths
linear in reproduction).

(See Archer's contribution.)

[Correspondence on Gregory & Whiteley.
[To face p. 40 P.

CORRESPONDENCE.

(Figs. A to D = Plate VIIIA.)

Mr. R. S. ARCHER (Republic Steel Corporation, Chicago, Ill., U.S.A.) wrote that he had been much interested in the paper. He regarded with admiration an ingot of this analysis which did not show cracks in rolling. He offered a few comments on the paper which might be of interest.

Two conclusions were expressed which seemed to him contradictory. One was that the occurrence of globular sulphide inclusions indicated emulsification before the freezing of the steel and that this had some connection with the good rolling properties of the steel. To the extent that a sulphide constituent was emulsified with the liquid steel, the sulphur in this constituent would not be present in solution in liquid steel and, therefore, would not lower its freezing point. This seemed to be inconsistent with the conclusion that the freedom from cracking was due to the widening of the freezing range.

That an excess of iron sulphide in itself was sufficient to prevent cracking seemed to be contradicted by a couple of ingots that Mr. Archer had made which broke up very badly. One of these contained 0·12% of carbon, 0·90% of manganese and 0·50% of sulphur; the other contained 0·11% of carbon, 0·98% of manganese and 0·53% of sulphur. Both were made by adding most of the sulphur in the mould during pouring. The addition of sulphur in the mould was, of course, poor practice, and was done only because these were experimental ingots. It was the usual practice in America to add the sulphur in the ladle.

Three micrographs which might be of interest were reproduced. These were from a bar containing 0·40% of carbon, about 1·5% of manganese and 0·11% of sulphur. Fig. A showed the normal structure of the bar as rolled. One end of this bar was then put in the door of an open-hearth furnace and allowed to come to the melting point. The cool end of the bar then showed elongated sulphides as before. Towards the hot end the sulphides assumed a globular form, and still further towards the hot end a eutectic form; these were shown in Figs. B and C, respectively. He had also noticed in the case of steel slightly over-heated before rolling some sulphides having an angular form, even after a fairly high reduction by rolling (see Fig. D). This he assumed to be an idiomorphic form of fairly pure MnS. The inclusions which elongated during rolling he assumed to be a solid solution of MnS and FeS.

In Fig. 23 of the paper was shown a sulphide formation which looked to him like a typical eutectic formation, although apparently it was not referred to as such. He would be interested in the authors' opinion on this point.

Dr. D. BINNIE (The Lancashire Steel Corporation, Ltd., Irlam, near Manchester) wrote that Mr. Whiteley had brought out the point that mild carbon steels had a tendency to develop cracks, although above 0·3% of carbon the liability of the ingot to crack tended to diminish.   He had developed a theory that the widening of the liquidus-solidus range acted as a stress-reliever and so diminished the tendency of the ingot surface to crack.

Practically none of the papers published on the freezing of steel ingots seemed to dwell on the fact that soft and mild steels at a temperature only slightly lower than the liquidus passed through a peritectic change.

Dr. Desch, in his paper on " The Delta Region in Carbon Steels," [1] in view of the fact that by far the greater proportion of the steel ingots made were influenced by the δ phase, recommended that a study of this high-temperature range should be undertaken with the best available resources.

In 1929, the paper by Andrew and Binnie [2] drew attention to this peritectic change and said that it must be considered in dealing with the freezing of mild steels; also that the peritectic reaction under consideration was not a sluggish one—the thermal point on cooling was sharp and suggestive of the sudden freezing of a liquid. Above 0·3% of carbon the peritectic reaction, while still present, was beginning to diminish in intensity.

The conditions of the phenomenon of cracking were therefore covered by the peritectic reaction, i.e., the carbon content associated with cracking, and also the fact that cracking occurred a few minutes after freezing or not at all.

It would seem that soft and mild steels therefore passed through two distinct freezing stages, giving rise to a double contraction, which could easily be an important factor in the cause of cracking.

The maximum amount of steel freezing at the peritectic temperature occurred at the extreme limit of the δ + γ field, 0·16% of carbon.   This maximum amount fell off rapidly towards zero at 0·10% of carbon and more gradually towards zero at 0·51% of carbon.   Steels within the range 0·15–0·22% of carbon were therefore the most susceptible to the influence of the peritectic change, a range in which snake cracks were most likely to occur on rolling ingots.

Perhaps some physicist could work out the effect on the steel of the peritectic reaction and show what its significance really was. At the moment it could be said that the reaction for many steels was not one of insignificant magnitude but was, under practical conditions, as distinct and sharp as the initial freezing point itself.

[1] C. H. Desch, Eighth Report on the Heterogeneity of Steel Ingots, p. 27, Iron and Steel Institute, 1939, Special Report No. 25.

[2] J. H. Andrew and D. Binnie, Third Report on the Heterogeneity of Steel Ingots, Journal of the Iron and Steel Institute, 1929, No. I., p. 346.

AUTHORS' REPLY.

In a written reply, the AUTHORS desired to express their gratification at the interest shown in the paper.

Dr. GREGORY wrote that, in regard to the influence of sulphur on the cracking of steel ingots of ordinary sulphur contents he agreed with Mr. Bacon (and Dr. McCance) that the higher the sulphur, the greater was the proneness to crack development, *but in dead-killed steels only.* The latter generally contained appreciable proportions of silicon and/or aluminium, but these elements were deliberately excluded in the manufacture of the quality of steel described in the paper. In making free-cutting steel of this type, apart from the influence of teeming speeds and temperatures, the manganese-sulphur ratio and final degree of deoxidation were matters of primary importance in regard to crack development. The steel must not be too dense, *i.e.*, not over-killed, if cracking during rolling was to be reduced to a minimum. With a manganese-sulphur ratio, in terms of " percentage," less than 2, the steel tended to disintegrate during rolling, *i.e.*, it became hot-short, but if this ratio exceeded 2 but did not exceed 3, little or no difficulty was encountered. If the manganese-sulphur ratio exceeded 4, however, the steel became too dense, resulting in exaggerated pipe and a greater tendency to crack development during the rolling of the ingots. Experience had shown that the most satisfactory results were obtained when the manganese-sulphur ratio lay between 2·0 and 2·5, although, as indicated in the paper, due cognisance must be taken of the iron-oxide contents of the finishing slag, which must govern the oxygen content of the molten steel beneath it. Mr. Bacon's remarks on the excellent rolling properties of a steel containing 0·35% of sulphur were most interesting, since they confirmed the claim made in the paper that steels of higher sulphur contents than those conforming to B.S.S. 32, Grade 4, having sulphur contents between 0·20 and 0·30%, possessed superior rolling properties. It would have been of interest to know the manganese content of the 0·35% sulphur steel described by Mr. Bacon.

Mr. Bacon was perhaps justified in his contention that lead functioned in a similar way to an increase in sulphur content, since it was clear from the micrographs that most of the sulphur in the ingot described in the paper existed in the form of isolated globular particles, and it was reasonable to suppose that lead, in view of its insolubility in molten steel, existed in the form of emulsified globular particles, although the latter might be sub-microscopic in the solid state. In comparing leaded and high-sulphur free-cutting steels, however, the important question of segregation at once arose. It had been shown in the paper that the sulphur segregation in the ingot examined was almost negligible and definitely much less than would have been anticipated.

Dr. Maddocks' remarks were somewhat confusing, since he was apparently under the impression that with less than 0·30% of carbon the tendency to segregation was less than in steels containing more than this amount. In this respect, he (Dr. Gregory) would refer him to Figs. 3 and 4 of his paper on " Anti-Piping Compounds and their Influence on Major Segregation in Steel Ingots," [1] where an astounding degree of segregation in regard to carbon, sulphur, phosphorus and manganese was revealed in untreated ingots containing 0·16% of carbon. Further, he (Dr. Gregory) ventured to suggest that Dr. Maddocks should re-read the Reports of the Heterogeneity of Steel Ingots Committee, in particular the Second Report, where it was definitely shown that the degree of segregation in the lower-carbon steels was of the same order as in those containing more than 0·30% of carbon. Dr. Maddocks considered that " the complicated peritectic reactions taking place at, or near, the liquidus temperature might cause segregation of elements that were present in very small quantities," but the steel ingot described in the paper contained less than 0·09% of carbon, so that it was difficult to see how the peritectic transformation could have much influence on segregation, since by the time the peritectic temperature was reached practically the whole of the steel would have solidified. Indeed, it was doubtful whether the peritectic change would be involved at all during the freezing of steel of this particular composition, as, apart from sulphur, the only other important constituent was manganese, most of which was linked up with the sulphur in the form of inclusions. The matrix of the steel could thus be regarded as commercially pure iron, whence it followed that the molten metal would freeze essentially as the δ-iron solid solution before the peritectic temperature was reached, particularly in view of Mr. Whiteley's contention that sulphur widened the liquidus-solidus range. Any subsequent transformation of the δ into $\delta + \gamma$ and finally into the wholly γ or austenite solid solution obviously then occurred in the solid state, and so could have little or no influence on " major " segregation.

Dr. Maddocks finally referred to the segregation in ingot No. 29, described in the Second Ingot Report as an ingot of basic free-cutting steel, and stated that the sulphur had segregated to an enormous amount, from 0·115% to 0·295%, but he (Dr. Gregory) wondered how Dr. Maddocks had arrived at these values, since the sulphur values ranged from 0·084% to 0·249%. Even this degree of segregation, however, was of far greater magnitude than that indicated in the present instance, but if reference was again made to the Second Report, it would be seen that ingot No. 29 contained, on the average, 0·10% of phosphorus and was cast into a mould of larger dimensions, viz., 66 cwt. Both these factors could not be ignored in a consideration of the relative degrees

[1] Gregory, *Journal of the Iron and Steel Institute*, 1940, No. I., p. 263P.

of segregation, and it had also been indicated in the paper that a 0·5% sulphur steel exhibited a lesser tendency to cracking than free-cutting steels of lower sulphur contents and, in this respect, the tendency to cracking could not be entirely dissociated from segregation.

He (Dr. Gregory) was in complete agreement with Professor Andrew regarding his views on the deoxidising effects of sulphur on liquid steel, although it was perhaps necessary to point out that, before freezing, some of the oxygen and sulphur was evolved as gaseous sulphur dioxide during the making of high-sulphur free-cutting steels, as evidenced by the smell during the casting of the ingots. The evolution of this gas, indeed, often influenced optical-pyrometer temperature readings, so that the indicated temperatures relating to teeming on such classes of steel should be treated with great reserve.

Dr. Hatfield's remarks were particularly welcome, and his mechanical test results on forged pieces from different parts of the ingot, given in Table A, were most interesting and should do much to dissipate the myth that sulphur tended to make steel both hot- and cold-short. Specimens from rolled bars from ingots of like composition had been up-ended both hot and cold, without the least sign of surface weakness or failure, thus affording ample confirmation of Dr. Hatfield's conclusions.

Dr. Hatfield's results clearly showed that, provided that the steel contained sufficient manganese, the influence of high sulphur contents on the tensile and impact properties of steel was almost negligible. In the past, the adverse influence of sulphur on the mechanical properties of steel had, in his (Dr. Gregory's) opinion, been too closely associated with the influence of high phosphorus contents, and it was time that the necessary distinction was stressed. Unlike sulphur, phosphorus existed in solid solution, thereby hardening the ferrite at the expense of its ductility and shock resistance. It was true that the introduction of small proportions of copper and chromium tended to negative this adverse influence on the properties of steel, but the detrimental effects of sulphur could be almost completely and more easily overcome by paying proper attention to the manganese-sulphur ratio.

Mr. Bull had, quite rightly, drawn attention to the fact that inclusions were not solely responsible for low impact figures on transverse test-pieces. He (Dr. Gregory) could assure him that this ingot was representative of many thousands of tons of steel of similar quality, and, although this was the first ingot to be sectioned, routine sulphur-print tests on blooms and billets had invariably revealed an almost complete absence of segregation.

Mr. Stevenson wanted a complete cast history, but, unfortunately, that was not available, because it was decided to offer this ingot to the Ingot Committee after it had been made in the usual routine manner. He felt, however, that Mr. Stevenson's request for oxygen

determinations on the relevant bath samples should be kept in mind in any future examination of ingots by the Committee.   His offer to examine the inclusions by the alcoholic iodine method was much appreciated, but it should be pointed out that, as intimated by Dr. Hatfield, the sulphur contents of the inclusions were just as important as their oxygen contents.   Quite frankly, in view of the known limitations of the iodine method, he (Dr. Gregory) doubted if oxygen determinations would do anything beyond confirming Mr. Whiteley's deductions from microscopic analysis.

Dr. Becker had asked how much aluminium was added to the steel and what was its inherent grain-size.   As indicated earlier in this reply, the answer to his first question was that neither aluminium nor silicon were used for deoxidation, but, nevertheless, the steel possessed an inherently fine grain, and tests on rolled bars gave a value of 6 on the McQuaid-Ehn scale.   Here, then, was one explanation for the really excellent impact values obtained by Dr. Hatfield.

The question of transverse bend tests on plates rolled from steel of the quality described in the paper, raised by Mr. Whiteley, would receive attention as soon as circumstances permitted.

Dr. Jay's remarks were very interesting, and it was hoped that he would be able to collaborate with his colleague, Mr. Stevenson, in an effort to arrive at some method of determining the absolute chemical compositions of the constituents of the inclusions.

In reply to Mr. Russell, the eccentricity or lop-sidedness could only be due to the fact that the one side of the ingot cooled faster than the other side, as would be evident from the fact that the moulds were arranged in two parallel rows and the ingot examined was selected from a position about half-way along the second row. Heat was therefore absorbed by this mould from, at first, two sides only, so that this must have had its influence on the depths of the columnar crystal zones.   After a while, however, the temperatures of the mould and ingot walls would become evened-out, since the casting pit was below ground level, and this afforded a rational explanation, as to why the central zone was not so off-centre as Mr. Russell might have anticipated.

Mr. Archer's comments were most interesting and highly appreciated.   So far as relative immunity from cracking was concerned, he (Dr. Gregory) could only repeat the claim made in the paper that, notwithstanding its exceptionally high sulphur contents, the free-cutting steel developed by Park Gate possessed excellent rolling and other properties.   During rolling, the scale readily came away from the surface and, during the final passes, the exposed surface was almost invariably free from seams or torn surfaces.

With Dr. Binnie's general conclusions regarding the cracking of steel ingots, and the importance of the peritectic transformation, he was in agreement, but failed to see what bearing these conclusions had in the present case, since, according to Dr. Binnie's hypothesis, the

tendency for cracking should be at a minimum in all steels with less than 0·10% of carbon, in which peritectic transformations should not occur. What he (Dr. Gregory) really wanted to know was the real reason why free-cutting steels of the type described in the paper should be less prone to fracturing or cracking than free-cutting steels of the B.S.S. 32, Grade 4 type, where the carbon contents were similar (about 0·10%) and the only major chemical difference was the sulphur content. He thought that a possible explanation was Mr. Whiteley's contention that an increase in the sulphur content resulted in a widening of the liquidus-solidus range, and, in this regard, agreed with Dr. Binnie, but he did not see how the peritectic reaction could be involved.

Mr. WHITELEY wrote that Mr. Bacon's experience on the effect of an increase in sulphur from 0·03% to 0·06% on ingot cracking was most interesting, as was also his statement that the addition of lead to high-sulphur steel minimised this trouble. These observations lent support to the views that he had outlined in the paper.

Dr. Maddocks and Dr. Binnie had both referred to the peritectic reaction, the one in connection with segregation and the other in relation to ingot cracking. It seemed to him (Mr. Whiteley) that in those respects the speed of the reaction had to be considered. If it was rapid, as the results obtained by Andrew and Binnie seemed to show, the effect of the peritectic change on segregation should be but slight compared with that of a wide temperature difference between the liquidus and solidus. On the other hand, a rapid re-action would increase the suddenness of the contraction stresses along the isothermal plane as it advanced in the ingot, for not only was there an acceleration of freezing at that temperature, as indicated by Dr. Binnie, but, also, the accompanying trans-formation of solid δ- to γ-iron was likewise accompanied by a decrease in volume. Yet he (Mr. Whiteley) was far from convinced that the peritectic change was of major importance in ingot cracking. In his experience ingots with a carbon content lower than 0·18% were much less prone to crack than those which came within the 0·18–0·24% range. That should not be so if the peritectic reaction were the dominant factor concerned, for, according to the Fe–C equilibrium diagram, the amounts of metal which solidified and of δ-iron which formed from γ-iron during the change at 0·15% carbon were the same as at 0·22% carbon.

He hoped that Professor Andrew would continue his studies of slag systems, especially those to which the inclusions found in steel might belong, for some of the work that he and his collaborators had done had proved of service, as indicated in Part II. of the paper. Without the aid of such investigations metallographic work on inclusions would be seriously handicapped.

Since both Dr. Maddocks and Mr. Archer had referred to state-ments in the paper for which they apparently held both authors

responsible, he felt it should be said that the two parts were written quite independently and without any collaboration, so that the conclusions reached by one author were not necessarily endorsed by the other. Yet he did not think any contradiction occurred. The two conclusions that Mr. Archer had mentioned as being at variance were not really so, for it was evident that in using the term globular inclusions Dr. Gregory meant those that were complex in character and not simply manganese sulphide. Moreover, he (Mr. Whiteley) had nowhere stated, nor could it be inferred from his remarks, that he considered the whole of the sulphur was in solution just before the metal solidified; there was no evidence to support such an assertion. Mr. Archer's micrographs were indeed excellent and of much interest. The group of sulphide particles shown in Fig. C definitely resembled the formation A that he (Mr. Whiteley) had described, but he was very doubtful whether the idiomorphic crystals seen in Fig. D were MnS, for that substance should flatten in hot-rolling, and according to Mr. Archer the crystals seen in Fig. D remained unchanged in shape. With regard to Fig. 23, the particles there shown probably belonged to a eutectic but, since he was not certain of that, he had thought it advisable to describe them as a formation.

NOTE ON THE RESISTANCE TO FURNACE ATMOSPHERES OF HEAT-RESISTING STEELS.[1]

By A. G. QUARRELL, Ph.D., F.Inst.P. (The University of Sheffield).

Paper No. 2/1941 of the Alloy Steels Research Committee.

Summary.

The application of the high-temperature method of electron diffraction to thin oxide films formed on a heat-resisting steel has shown that at temperatures up to 950° C. the oxide has a spinel structure. This is possessed by a large number of oxides of the general type $XO.Y_2O_3$, and is both exceedingly flexible and inherently stable. It is suggested that the oxidation resistance of heat-resisting steels is largely due to the formation of a stable spinel. Provided that such elements as nickel, chromium and aluminium are present in sufficient quantities, the spinel structure should be stabilised, and the absence of lattice changes on heating and cooling will prevent easy access of oxygen to the underlying metal surface and so greatly increase the oxidation resistance. Similarly, the fact that a number of mixed sulphides possess the spinel structure permits of a possible explanation of the performance of heat-resisting steels in sulphurous atmospheres.

In the Second Report of the Alloy Steels Research Committee, Section IV.,[2] an account was given of a new technique of electron diffraction for examining iron-oxide films at the temperature of formation. It was shown that the Fe_3O_4, which was stable below about 400° C., was converted to FeO on heating above 500° C., and this oxide was stable up to the critical point of the ingot iron. Between 400° and 500° C., either Fe_3O_4 or FeO, or a mixture of the two oxides, was obtained, depending upon the thickness of the film. Between 515° C. and the A_3 change point the initial film consisted of a new hexagonal oxide bearing an intimate structural relationship with the underlying iron lattice, but further oxidation led to the formation of normal FeO. Above the A_3 point the oxide was Fe_3O_4. On cooling to room temperature, the oxide invariably reverted to Fe_3O_4, and therefore at least two transformations occurred in the oxide film on heating to, or cooling from, 950° C. Since there is no simple relationship between the FeO and Fe_3O_4 structures, these transformations must necessarily cause some

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[1] Received March 26, 1941.
[2] *Iron and Steel Institute*, 1939, *Special Report No. 24.*

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disruption of the oxide film and so facilitate the passage of oxygen from the atmosphere to the underlying iron surface, thus leading to further oxidation.

The high-temperature technique has since been applied between room temperature and 950° C. to a heat-resisting steel of the following composition :

Carbon.	Manganese.	Silicon.	Nickel.	Chromium.	Molybdenum
0·47%	0·72%	1·7%	12·9%	13·1%	3·1%

Whereas with the ingot iron a single volume of 3 c.c. of air sufficed to cause the formation of an oxide film which gave a well-defined diffraction pattern, at least 10 or 20 volumes were necessary with the heat-resisting steel. It was found that at all temperatures of formation and examination, for films of various thicknesses up to that corresponding to 100 volumes of air, the oxide film gave an electron-diffraction pattern corresponding to a spinel structure, but with very small crystal size. The spinel structure with a complicated cubic unit cell is possessed by a large number of compounds including, for example, Fe_3O_4. Moreover, the lattice parameters of the different spinels differ only slightly from one another, and therefore it is not possible to decide from electron-diffraction data the exact nature of the spinel observed on the heat-resisting steel. As will be shown later, it is probable that any attempt to assign a particular composition to the spinel oxide would be foredoomed to failure, but it can safely be assumed that it is not Fe_3O_4, since the experiments on ingot iron show that this is stable only below 450° C. and above 900° C. It was at first thought that selective oxidation had occurred and that a film of nickel chromite, $NiO.Cr_2O_3$, had been formed, but a consideration of the various spinel structures already known to exist suggests an alternative and more interesting explanation.

The spinel structure is possessed by a very large number of oxides of the type $XO.Y_2O_3$, where, according to classical conceptions, X is a divalent and Y a trivalent metal atom. In addition, natural spinel minerals are found in which the X positions on the lattice are shared among two or more metals, not always in the same proportions, e.g., chromite, $(Fe,Mg)O.Cr_2O_3$, and jacobsite, $(Mg,Mn,Fe)O.Fe_2O_3$. More recently, in order to explain the abnormal intensities observed in the X-ray patterns from spinels it has been found necessary to assume [1] that the X atoms may even change places with those normally occupying the Y positions. Indeed, spinels have been observed in which the Y positions are all occupied by atoms which are normally regarded as divalent, e.g., $TiO.Zn_2O_3$ [2]

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[1] Wyckoff, " Supplement to ' The Structure of Crystals,' " p. 69. New York, 1935 : Reinhold Publishing Corporation.

[2] Holgersson and Herrlin, *Zeitschrift für anorganische Chemie*, 1931, vol. 198, p. 69.

and $SnO.Zn_2O_3$.[1] Spinels have already been observed with molybdenum, cadmium, cobalt, copper, iron, magnesium, manganese, tin, titanium or zinc in the X position, and silver, aluminium, cobalt, chromium, iron, gallium, indium, magnesium, manganese, nickel, vanadium or zinc in the Y position.   The spinel structure is also possessed by both γ-Fe_2O_3 and Fe_3O_4.

The foregoing facts make it clear that the spinel structure is exceedingly flexible, and at the same time it must be inherently stable, otherwise the introduction of a new type of metal atom into the lattice would cause a change in dimensions or even a conversion to a different structure. The lack of protection afforded by the spinel $FeO.Fe_2O_3$ on ingot iron and plain carbon steels must be regarded as exceptional and attributed to the fact that both the X and Y positions are occupied by iron atoms, thus making it possible for the lattice as a whole to be converted to the lower oxide FeO.[2] With the more general type of spinel, containing at least two different metals, a corresponding change is impossible, and therefore the structure should be stable over a much wider range of temperature. Consequently, on heating or cooling there will be no disruption of the lattice and there will be no time at which oxygen will be able to pass freely through newly developed cracks to oxidise the underlying metal.   An example of a truly protective spinel film is afforded by nickel-chromium alloys.   The oxide formed on an 80/20 nickel-chromium alloy has been shown by electron diffraction to consist of $NiO.Cr_2O_3$, and there can be no doubt that the spinel affords excellent protection against corrosion in this case.

On the assumption, therefore, that a spinel oxide containing two different metals does, under suitable conditions, confer protection, it is possible to build up a theory to explain the resistance to furnace atmospheres offered by heat-resisting steels.   Consider what happens when the amount of alloying elements—say, nickel and chromium—is gradually increased from zero, and oxidation occurs in air at 950° C. With pure iron the oxide formed will consist of Fe_3O_4, and even when small quantities of nickel and chromium are present the oxide will still behave as if it were Fe_3O_4 and will be converted to FeO on cooling below about 900° C. Eventually, with higher contents of the alloying metals, the nickel and chromium will take control and stabilise the spinel structure. The steel will then show considerable resistance to oxidation, although, of course, its mechanical properties at high temperatures may not be satisfactory.   In order to obtain the necessary mechanical properties at high temperatures it may be necessary to add other alloying elements, and the question arises as to whether these additional elements will have a deleterious effect upon the corrosion

[1] Barth and Posnjak, *Zeitschrift für Kristallographie*, 1932, vol. 82, p. 325.

[2] Even $FeO.Fe_2O_3$ affords protection in certain temperature ranges, *e.g.*, blueing of boilers.

resistance. As will be seen from the list of already investigated spinels (Table I.), however, any metal used or likely to be used as

TABLE I.—*Oxides and Sulphides known to Possess a Spinel Structure.*

	Oxides.	
$CdO.Cr_2O_3$	$MgO.Al_2O_3$	$SnO.Co_2O_3$
	$MgO.Co_2O_3$	$SnO.Mg_2O_3$
$CdO.Fe_2O_3$	$MgO.Cr_2O_3$	$SnO.Zn_2O_3$
	$MgO.Fe_2O_3$	
$CoO.Al_2O_3$	$(Mg,Mn,Fe)O.Fe_2O_3$	$TiO.Fe_2O_3$
$CoO.Co_2O_3$	$MgO.Ga_2O_3$	$TiO.Mg_2O_3$
$CoO.Cr_2O_3$	$MgO.In_2O_3$	$TiO.Mn_2O_3$
$CoO.Fe_2O_3$		$TiO.Zn_2O_3$
$CoO.Mn_2O_3$	$MoO.Ag_2O_3$	
		$ZnO.Al_2O_3$
$CuO.Al_2O_3$	$MnO.Al_2O_3$	$ZnO.Co_2O_3$
$CuO.Co_2O_3$	$(Mn,Co)O.(Co,Mn)_2O_3$	$ZnO.Cr_2O_3$
$CuO.Fe_2O_3$	$MnO.Cr_2O_3$	$ZnO.Fe_2O_3$
	$MnO.Fe_2O_3$	
$FeO.Al_2O_3$		
$FeO.Cr_2O_3$	$NiO.Al_2O_3$	
$(Fe,Mg)O.Cr_2O_3$	$(Ni,Co)O.(Co,Ni)_2O_3$	
$FeO.Fe_2O_3$	$NiO.Cr_2O_3$	
$FeO.V_2O_3$	$NiO.Fe_2O_3$	
	Sulphides.	
$CdS.Cr_2S_3$	$CuS.Co_2S_3$	$NiS.Ni_2S_3$
$CoS.Co_2S_3$	$MnS.Cr_2S_3$	$ZnS.Cr_2S_3$
$(Co,Ni)_3S_4$		

an alloying element in a heat-resisting steel can take up either the X or Y position in the spinel lattice, and it is at least highly probable that, once the spinel has been stabilised, it can accommodate any of the metals likely to be encountered. If this view is correct, the composition of the oxide film on a heat-resisting steel will depend upon the composition of the steel, and no exact formula corresponding to $FeO.Fe_2O_3$ can be assigned to it.

In practice, a heat-resisting steel is usually subjected to furnace atmospheres containing sulphur, and therefore it might be thought that the foregoing observations can have little bearing on the behaviour of such steels under industrial conditions. Further reference to the list of spinel structures (Table I.) shows that mixed sulphides can also form spinels. It is true that these sulphides have a rather larger unit cell than the corresponding oxides, but nevertheless it is probable that in a sulphurous atmosphere the spinel layer formed on a heat-resisting steel will be a mixed sulphide-oxide spinel. In other words, it is possible to visualise a spinel structure which can accommodate not only the various metals contained in the steel but also the oxygen and sulphur in the proportions in which they occur in the furnace gases. Such a spinel

would be expected to withstand cyclic temperature changes without breakdown of the lattice, and, furthermore, changes in the composition of the furnace gases might quite well be counterbalanced by the interchange of sulphur and oxygen atoms. If this were so, then the spinel would automatically adopt a composition which would be in equilibrium with the atmosphere, without at the same time breaking up or allowing excessive corrosion.

It should be noted that the stable spinel, whether oxide or oxide-sulphide, could contain a large proportion of iron, provided that sufficient alloying constituents were present to prevent the reversion to FeO on cooling.

One would not expect to observe a great difference in the protection afforded by spinels of different compositions, but the stability of the spinel at high temperatures would be determined by its composition, and it is from this point of view that the composition of a heat-resisting steel may possibly be critical in so far as oxidation resistance is concerned.

It is known from experience that protective oxide films are invariably amorphous or have a very small crystal size, as was the case with the heat-resisting steel examined. Heat-resisting alloys containing fairly large proportions of aluminium have proved very successful, and there is a tendency to attribute this to the formation of an amorphous aluminium-oxide film such as is known to be formed on aluminium, and which is probably the most protective oxide film known. That this explanation is probably incorrect can be seen from the work of Preston and Bircumshaw,[1] who showed that the amorphous aluminium oxide becomes crystalline, and therefore loses much of its protective power, at about 700° C. On the other hand, aluminium may be regarded as a powerful stabilising element, since it forms spinel oxides with cobalt, iron, manganese or nickel in the X positions, and it may well be that heat-resisting steels containing aluminium owe their corrosion resistance to the formation of a particularly stable spinel oxide film.

Many heat-resisting alloys contain a large percentage of silicon, and in this case the protective layer could well be amorphous. Amorphous silica is stable and protecting over a remarkable range of temperatures, as is indicated by a series of electron diffraction experiments carried out by Finch.[2] On removal from the electric arc furnace in which they are made, silicon-carbide crystals are found to be coated with a thin, invisible amorphous silica film, which protects the crystal from further oxidation. If the silica film is removed and the crystal is then heated gently in a Bunsen flame, it immediately becomes coated once more with a similar invisible film. It can therefore be concluded that the amorphous

[1] Preston and Bircumshaw, *Philosophical Magazine*, 1936, vol. 22, p. 654.
[2] Finch, *Journal of the Chemical Society*, 1938, p. 1140.

silica film is extremely protective and at the same time is stable even at very high temperatures.

Acknowledgments.

DISCUSSION.

This paper was presented for discussion at a Joint Meeting of the Institute with the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association held at the Royal Victoria Station Hotel, Sheffield, on Saturday, October 4th, 1941, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of the Institute).

Mr. H. J. GOLDSCHMIDT (Messrs. William Jessop & Sons, Ltd., Sheffield) said that Dr. Quarrell stated that transformation from FeO to Fe_3O_4 and *vice versa* " must necessarily cause some disruption of the oxide film and so facilitate the passage of oxygen from the atmosphere to the underlying iron surface, thus leading to further oxidation, the reason being that there is no simple relationship between the FeO and Fe_3O_4 structures." In fact, however, there existed a very close relationship between the two lattices, which went much beyond the common feature of cubic symmetry. Jette and Foote [1] had shown this in their X-ray work. It could be proved that in the iron-oxygen system the transition from FeO to Fe_3O_4 took place by a simple atomic rearrangement and the whole wüstite solid solution of oxygen in FeO could be regarded as a stage preparatory to the change-over to Fe_3O_4. Iron atoms were dropped from the FeO lattice, and partial ionisation from divalent to trivalent iron already occurred. Even during the transformation to the spinel structure the atomic readjustments were such that the fundamental cubic framework of divalent iron atoms retained its identity in both lattices. The Fe_3O_4 structure had 56 atoms per unit cell, of which 32 were oxygen and 24 iron atoms. Comparing the two compounds, there was the same number of oxygen atoms per lattice volume (32), but a decrease in iron, in continuation of the dropping of iron atoms from the lattice already initiated within the wüstite range. He had studied the mechanism of this transformation closely, but the details were immaterial in this connection.

The main point that he wanted to make was that, owing to this quasi-continuous mechanism of transition from the FeO to the Fe_3O_4 structure, it appeared probable that segregation of spinel crystallites within a parent crystal of the sodium-chloride type of structure might take place without causing a physical disruption of the oxide film. The function of certain alloying elements such as nickel or chromium might actually be not only, as Dr. Quarrell suggested, to stabilise the spinel structure, but also to aid the maintenance of this grain continuity between the two compounds during precipitation and to eliminate differences in atomic volumes, so as to minimise any tendency to disruption which might still exist with pure FeO and Fe_3O_4. Dr. Quarrell found that the crystallites of the spinel structure formed on the heat-resisting

[1] *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1933, Iron and Steel Division, vol. 105, p. 276.

steel were of very fine crystal size, and it seemed likely that they would have the same orientation as the original FeO crystal, a point which would be interesting to verify.

Regarding the suggested formation of oxide-sulphide spinels as a protective layer in sulphur-containing atmospheres, he would be interested to know whether such mixed spinels had ever been observed. No references in the literature appeared to contain evidence for them, only for pure oxides and pure sulphides, and it seemed rather doubtful whether the much larger sulphur atoms would readily replace those of oxygen without disturbing the stability of the lattice. Apart from that, the known sulphur spinels never contained iron as one of the cations, which was indicated in Dr. Quarrell's Table. Would not iron more probably combine with the sulphur to form pyrrhotite (FeS), if the temperature conditions permitted ? Pyrrhotite lost iron atoms in a similar manner to wüstite, as Hägg[1] had shown. It was of hexagonal structure and might conceivably have a relation to the metastable hexagonal oxide which Dr. Quarrell found by electron-diffraction, so that possibly the presence of sulphur would enhance the formation and stability of the latter (assuming now that sulphur and oxygen were readily replaceable).

Dr. A. H. JAY (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) said that this paper was both intriguing and startling. In making his contribution he thought it was only right to emphasise that, while the author had examined very thin oxide scales, incidentally so thin that technical steelworkers might describe them as tints, he had studied scales, of thickness varying from less than 0·0001 in. to 0·002 in., produced in mill and laboratory furnaces, and which could be assessed by the use of a delicate balance. This distinction suggested the following questions concerning the use of the word " protective " : Did the author consider the observed oxide film on this nickel-chromium steel to be protective because of its slower rate of formation as compared with that on iron ? Further, had the author examined films of increasing thickness such as would be produced, say, by a longer time of heating in contact with air ?

The conclusions reached by the author on the character of a protective scale and the theme developed appeared quite contrary to the speaker's own experience and belief, which could be stated thus : The character of the scale was influenced by the oxygen content of the furnace atmosphere, and a simple oxide appeared to offer better protection than one which was more complex. Examples would now be given : Iron alloys containing aluminium when heated in air gave an alumina coating which was highly crystalline, and when cracks were absent in the metal surface the rate of increase of the oxide film was very slow. This was true whether the steel

[1] *Nature*, 1933, vol. 131, p. 167.

was kept at a steady temperature or repeatedly quickly heated and cooled as in the accelerated life test for resistance wires. Only when the oxide film changed its simple character and iron oxide appeared did the steel show a rapid rise in scale formation. Therefore for aluminium steels, with the aluminium content as low as 4–5%, the protective oxide was a simple one—alumina.

Dr. QUARRELL did not think that Dr. Jay was in a position to say that it was pure alumina which gave protection, because if there were a thin film of the type that he was suggesting Dr. Jay could not detect it.

Dr. JAY replied that he was not examining extremely thin films or layers but scales from 0·00005 to 0·002 in. in thickness. The alumina which he found was pure alumina in the sense that there was no solid solution with other refractory oxides such as Fe_2O_3. On the other hand, when iron-aluminium alloys were heated in an atmosphere of low oxygen content the oxides alumina and ferrous oxide were formed, which reacted with the formation of a spinel, $FeO.Al_2O_3$. The observed result of the scale formation was that the steel scaled away at an unbelievedly fast rate. The spinel had therefore offered no protection.

Dr. W. H. HATFIELD, F.R.S. (Brown-Firth Research Laboratories, Sheffield) asked if Dr. Jay could put that forward and implement it with his X-ray pictures?

Dr. JAY replied that he could, if he obtained the permission of the firm for whom the work had been done.

Austenitic nickel-chromium steels (he continued), when heated in mill or laboratory furnaces, gave an oxide which might be Fe_2O_3 or a mixture of Fe_2O_3 and Fe_3O_4 (the Fe_3O_4 might not be 100% pure, but it was found that the nickel and chromium contents were usually very low). When only Fe_2O_3 was found the scale was very thin, but where Fe_3O_4 was the major constituent the scale was thicker and had a tendency to flake off.

The statement that spinels differed only slightly in lattice spacings was strictly not true, and it was possible in X-ray work to determine changes in the character and composition of a spinel by changes in the lattice spacing. He would agree that it would be difficult to decide the nature of the oxide film examined by the author, bearing in mind the possible combinations, $FeO.Cr_2O_3$, $NiO.Cr_2O_3$ and $FeO.Fe_2O_3$, as allowed by the steel composition.

The reference to the oxide spinel $NiO.Cr_2O_3$ on nickel-chromium alloys and the stated occurrence of a nickel-sulphide spinel seemed unfortunate when viewed in the light of the known fact that these alloys were severely scaled in atmospheres containing sulphur. Incidentally, the oxide produced on these alloys by heating to

1000° C. for 60 hr. in air was found by X-ray examination to be mainly Cr_2O_3 with a very small amount of a spinel structure.

It would be an advantage to readers of the paper if the author could amplify the experimental section. He looked forward to this work being continued on scales of increasing thickness.

Mr. J. H. G. MONYPENNY (Messrs. Brown Bayleys' Steel Works, Ltd., Sheffield) said that he had been very interested in the paper. Whether the theory propounded turned out to be right or wrong, at least it was a working theory, and that was a very big advantage to have when one was tackling a problem that seemed rather complex.

Dr. HATFIELD said they might disagree with Dr. Quarrell on his deductions, but at any rate they had there the latest method of attack brought to bear on one of their most intricate and immediate problems. He was sure he voiced the general feeling when he said that they would like to see the work continued, and that a number of them would be very glad to collaborate in supplying the author with samples prepared under special conditions if he would like them to do so.

CORRESPONDENCE.

Mr. A. PREECE and Mr. R. V. RILEY (Leeds University) wrote saying that they were particularly interested in the valuable work of Dr. Quarrell, because they also were studying the high-temperature oxidation of steels. It would appear that the author attributed scaling resistance to the formation of a spinel structure and they would like to know on what evidence the author based this conclusion. They thought that any theory which would explain heat resistance should take into account concentration gradients in the protective oxide films, and they would ask whether it was necessary to assume a spinel formation to account for heat resistance, since this latter property might well be the result of a low diffusivity of the oxide layer for the constituents of the steel and the furnace atmosphere.

Further evidence would also be welcomed in support of the author's statement that amorphous films were more protective than the crystalline type.

AUTHOR'S REPLY.

Dr. QUARRELL, in reply, wrote thanking those who had contributed to the discussion. It was important to remember that electron-diffraction had shown that when the $FeO \rightleftarrows Fe_3O_4$ trans-

formation occurred on heating and cooling, oxidation of the metal specimen proceeded rapidly, whereas if the oxide film retained its spinel type of structure at all temperatures oxidation was slow. This was experimental fact, and the first part of Mr. Goldschmidt's remarks had been concerned with the theoretical explanation of this experimental fact.   He (Dr. Quarrell) had not been familiar with the results obtained by Jette and Foote which were quoted by Mr. Goldschmidt, but it seemed that these results would help to explain the increased oxidation occurring when .the $FeO \rightleftarrows Fe_3O_4$ transformation took place.   On changing from FeO to Fe_3O_4, eight atoms of iron were precipitated for each unit cell of Fe_3O_4 formed. These iron atoms would be in an exceedingly active state, and any such atoms precipitated near the oxide-oxygen interface would rapidly combine with oxygen atoms.   Conversely, when the Fe_3O_4 reverted to FeO eight iron atoms would be taken in by each unit cell, and these atoms could be supplied only by the steel substrate.   Consequently, repeated heating and cooling through the $FeO \rightleftarrows Fe_3O_4$ transformation would result in a transfer of iron atoms from the metal to the oxide-oxygen interface, with consequent increase in thickness of the oxide layer.   Mr. Goldschmidt had suggested that the function of alloying elements might be to minimise any disruption which occurred on changing from FeO to Fe_3O_4 and *vice versa*, but this ignored the fact that no evidence had been obtained for the existence of FeO at any time on the heat-resisting steel. For the same reason it was not possible to answer Mr. Goldschmidt's question concerning the orientation of the spinel structure on heat-resisting steel.   The Fe_3O_4 formed on ingot iron and plain carbon steel, however, had been found in earlier work by Jackson and Quarrell [1] to possess the same orientation as the FeO; that was, when the FeO existing between about 500° and 900° C. was in cube-face orientation, the Fe_3O_4 crystals formed on cooling were also in that orientation, and, furthermore, the degree of departure from perfect orientation was the same in both cases.

It was true that mixed oxide-sulphide spinels had not yet been observed, but it must be remembered that X-ray investigations were carried out on relatively massive specimens.   The results so far obtained with extremely thin films of the type which could be examined by electron-diffraction indicated that abnormal structures and properties were to be expected with such thin films, and mixed oxide-sulphide spinels might be possible.   He agreed that replacement of oxygen atoms by sulphur must result in some disturbance of the lattice.   It was not suggested that sulphur replaced oxygen in the spinel structure with all compositions of steels and all furnace atmospheres.   It was likely that straightforward sulphides such as FeS or NiS would be formed in many cases.

With regard to Dr. Jay's contribution, he believed that the

[1] Second Report of the Alloy Steels Research Committee, *Iron and Steel Institute*, 1939, *Special Report No. 24.*

majority of the discrepancies between Dr. Jay's results and his own were only apparent, and were due to the difference in method of examination employed.   The rate of oxidation of a metal specimen in a given atmosphere must ultimately depend upon the nature of that layer, only a few atoms thick, which was in immediate contact with the metal.   He believed that this layer was the first oxide film to be formed, and that further oxidation led to the formation of a relatively thick film of secondary oxidation products on the outside of this layer.   By examining specimens after fairly mild oxidation treatment it was possible to obtain electron-diffraction evidence concerning the structure of the initial film.   By the time the oxide was sufficiently thick for X-ray investigation, however, a much greater thickness of the secondary oxidation products had been built up, and these were the oxides which Dr. Jay examined.   This could be illustrated by one of the results quoted by Dr. Jay.   According to him, the oxide film on an austenitic nickel-chromium steel, which possessed good oxidation-resistance properties, was pure Fe_2O_3 ; yet a similar film of Fe_2O_3 could be present on a plain carbon steel without producing any measure of oxidation resistance. If Dr. Jay's contention that he examined the protecting oxide film was admitted, it was necessary to explain why the Fe_2O_3 was protecting in one case and not in the other, and apparently Dr. Jay could not put forward an explanation.   According to the author's views, however, the explanation was relatively simple.   The first film formed on the alloy steel was probably a spinel oxide containing nickel, chromium and iron atoms.   As exposure to oxidising conditions continued, iron atoms would diffuse through the spinel oxide and form an outer layer of Fe_2O_3.   For some time the tendency would be for the spinel layer to become richer in nickel and chromium and so more protective.   The thickness of the Fe_2O_3 layer would increase at a rate which was determined mainly by the rate of diffusion of iron atoms through the spinel lattice, but the spinel layer itself would remain of virtually constant thickness.   When examined by X-rays no evidence of the existence of the spinel film would be obtained, because of its extreme thinness ; instead, the pattern would correspond to Fe_2O_3 alone, which, as stated previously, should be regarded as the secondary oxidation product.   Similar considerations would apply to the other examples quoted by Dr. Jay.   In addition, Dr. Jay's specimens were examined after cooling to room temperature, whereas the electron-diffraction results were obtained with the oxide film at the temperature of formation, as described in detail in Section IV. of the Second Report of the Alloy Steels Research Committee (*loc. cit.*).   Bearing these differences in mind, there appeared to be no real conflict between the results obtained by Dr. Jay and by the author, but, instead, very good reason why there should be closer co-ordination of X-ray and electron-diffraction methods in the future.

Replying to Mr. Preece and Mr. Riley, when a heat-resisting

nickel-chromium steel specimen was oxidised in the electron-diffraction camera at various temperatures up to 950° C. it was found that much greater volumes of air were needed to produce a detectable film of oxide than were necessary with plain carbon steel specimens, and the oxide films invariably had the structure of a spinel. These films were very much thinner than those which Mr. Preece and Mr. Riley would normally examine, and, as the results quoted by Dr. Jay indicated, it would appear that with thicker oxide scales the outer layers would have the structure of Fe_2O_3.

The statement that amorphous films were more protective than the crystalline type had been made as the result of the electron-diffraction examination of films which were generally admitted to be highly protective. Thus, the oxide film on aluminium, the passive film on iron, the natural oxide on chromium and on stainless steel were all amorphous as judged by their electron-diffraction patterns. The oxide film on aluminium foil was particularly interesting, because on heating to a sufficiently high temperature the outer layers of oxide became crystalline, although a thin film of amorphous oxide still remained in intimate contact with the metal. It was, of course, not possible to assign any chemical formula to the amorphous oxides, but it was probable that the proportion of metal in such oxides was higher than in recognised oxides. Other examples of protective oxide films which were amorphous have been given by Finch.[1]

In conclusion, Dr. Quarrell wished to stress the point that it was not intended to suggest that in all cases the oxidation resistance of heat-resisting steels was to be attributed to the presence of a spinel oxide on the metal. The presence of such a film might afford protection in many cases, however, and the object of the paper was to draw attention to this possibility and so to help in formulating a working theory which might lead to a better understanding of the oxidation resistance of alloy steels.

[1] *Journal of the Chemical Society*, **1938**, p. 1140.
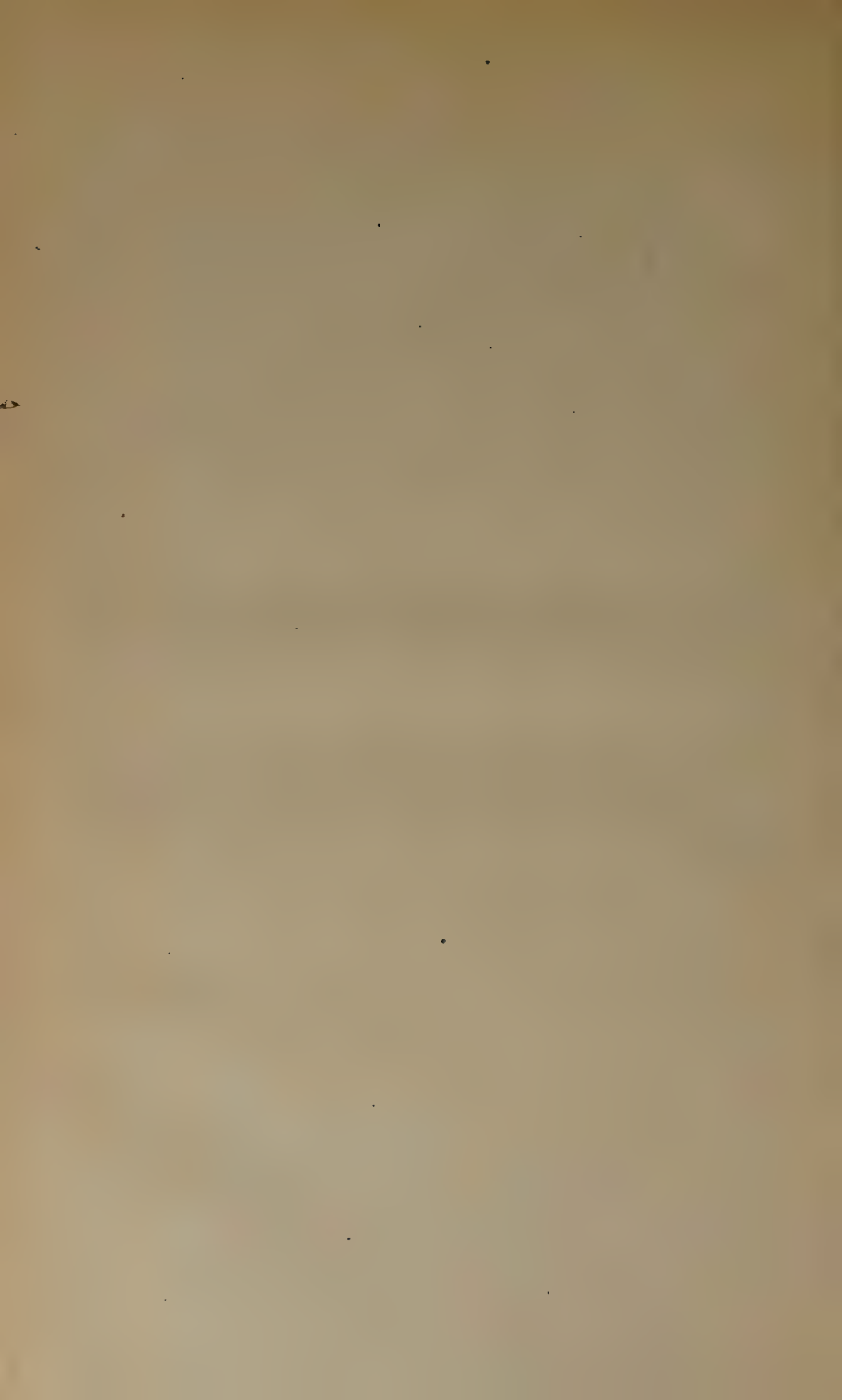
APPARENT RELATIONS BETWEEN MANGANESE AND SEGREGATION IN STEEL INGOTS.*

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Paper No. 8/1941 of the Committee on the Heterogeneity of Steel Ingots.

Summary.

An examination has been made of the relations of manganese to segregation in all the plain carbon steel ingots which have been examined and described by the Committee on the Heterogeneity of Steel Ingots. As a result the following four tentative conclusions have been reached :

(1) The ratio of the manganese increase to that of the sulphur is as a rule higher in sound than in unsound ingots.

(2) Carbon, phosphorus and sulphur may all carry some excess of manganese in segregating, their total atomic increments being directly proportional to the percentage increase of manganese in both sound and unsound ingots, although in the latter there is a lesser proportion of extra manganese, probably owing to gas evolution. The inference is drawn that all three elements exist largely as compounds of iron and manganese in the liquid steel near the freezing point.

(3) In sound ingots a linear relationship appears to obtain between the ratio of the increment of manganese to the total increment of carbon, phosphorus and sulphur and the ratio of manganese to these elements at position E (at the base of the cavity in the ingot head).

(4) Segregation is diminished as the ratio of the manganese to the carbon, phosphorus and sulphur in the steel is increased.

Distributed through the many Reports of the Committee on the Heterogeneity of Steel Ingots are to be found descriptions of about seventy steel ingots, the extent of the segregation in which has been thoroughly investigated.[1] These ingots vary widely in size, their weights ranging from $\frac{1}{2}$ ton to 172 tons, and since the utmost care has been exercised to ensure that, in each instance, the results should be trustworthy, the work may be considered as thoroughly representative of steelmaking practice. This large and costly collection of information invited more examination than had yet been given to it, in order to ascertain whether the data disclosed features connected with segregation other than those noted in the

Reports, and the present paper records an attempt made in that direction.

In plain carbon steels, which are alone dealt with, there are four segregating elements, *viz.*, carbon, phosphorus, sulphur and manganese, and of these the first three are fairly consistent in their behaviour, but that of manganese is unmistakably erratic ; in some ingots the increment is quite large, while in others it is comparatively slight, even when the segregation is obviously pronounced. The one or more underlying causes of this variability on the part of manganese are still obscure and the primary object of the investigation was to elucidate this problem. It must be emphasised, however, that none of the conclusions reached should be regarded as final ; to establish them beyond question they need more confirmation.

In judging the amount of segregation in each ingot, differences between the analyses at standard positions along or in the vicinity of the axis, as indicated in Fig. 1, have alone been considered.
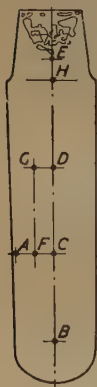

This procedure is warranted by the fact that most, if not all, of the major segregation at positions H and E is derived from the lower interior portion, for the analyses along the outer parts correspond fairly closely to that of the pit sample. Rimming steel ingots provide the only exception to this rule, but even in these a rise of segregate in the core is generally evident, although the changes in composition are usually less than those between rim and core. Since in the majority of examples given by the Committee the manganese content does not increase on passing from rim to core, this peculiar form of segregation is not studied, attention being confined entirely to the central zone.

It should here be remarked that the analyses of the ingots were for the most part carried out by the firms that contributed them, and quite possibly check determinations made in another laboratory would not always have given identical results. Relatively small discrepancies in the carbon, sulphur and phosphorus estimations would not, however, invalidate the conclusions reached ; only in the case of manganese would the effect be sometimes appreciable. Fortunately, the correct determination of this element in plain carbon steels presents little difficulty, for the accuracy of each of the several methods available is now well established. Moreover, the most likely error in any set of analyses would be one common to all determinations of an element, due, say, to the blank, so that the increments would not be affected, and it is with these that most of the observations are concerned. Hence the author feels confident that the conclusions drawn rest on a reasonably sound basis and these will now be dealt with in the following four items.

Fig. 1.— Positions from which Analytical Samples were taken.

(1) In all the ingots examined by the Committee, with the exception of Nos. 62 and 65 and possibly Nos. 24, 25, 29 and 42, it may be regarded as certain that the whole of the insoluble sulphide in the segregate was present as MnS, and since the weight ratio of manganese to sulphur in that compound is 1·72, the ratio of the manganese increment to 1·72 times the sulphur increment should not be much less than 1·0. This is by no means the case, as the figures in the last column of Table I. will show. As there indicated, these ratios were obtained by dividing the difference between the manganese contents at the highest and lowest sulphur positions along the axes of the ingots by 1·72 times the sulphur increment. The percentages of manganese at the above positions were used in all but a few instances contained in the First Report, where a large number of analyses had been made and where the following slight alterations seemed warranted. In examples Nos. 2 and 3 the highest sulphur contents are very near the top surfaces and there some of the manganese seems to have been removed by air oxidation, judging by adjacent percentages; the figure immediately below seemed to be more representative and this was accordingly taken. In example No. 6 the manganese content shown at the lowest sulphur position is distinctly higher than several surrounding figures and, for this reason, the percentage stated in Table I. is an average of seven adjacent results including, of course, that under suspicion. Owing to a similar uncertainty, an average of three neighbouring determinations is given in the case of example No. 11.

On examining the ratios thus found it was noticed that, while many were above 1·0, those for the rimming steel ingots were without exception very low, four in fact being a minus figure. This fact suggested that the quantity of gas liberated during solidification had an influence on the amount of manganese carried by the segregate; and on grouping the ingots in three classes, viz., sound, nearly sound and unsound, as in Table I., indications of a connection between the one occurrence and the other became still more apparent. It will be seen that of the twenty-six sound ingots, twenty-one gave a ratio higher than 1·0, whereas the ratios for each of the twenty-one unsound ingots are below 1·0, eighteen being less than 0·5. Moreover, in the sound ingot No. 6, one of the five exceptions, the ratio could be raised above 1·0 by taking 0·756%, an adjacent manganese result, instead of 0·777% as the figure for the lower sulphur position. It should also be mentioned, in passing, that in the case of another exception, ingot No. 48, calcium silicide was used as a deoxidiser. Thus sound and unsound ingots could on the whole be well distinguished by arbitrarily selecting a ratio of 1·0 as the dividing line, and further justification for this conclusion is derived from the fact that the ratios in all five nearly sound ingots are in the vicinity of that figure.

Apart from gas evolution no other reason can be advanced for

TABLE I.—*Relationship between the Segregation of Manganese and of Sulphur.*

No.	Weight. Tons.	C.C. %.	Si. %.	Axis.				Ratio of the Manganese Increment to the Sulphur Increment × 1·72.
				Lowest S Position.		Highest S Position.		
				Mn. %.	S. %.	Mn. %.	S. %.	
					Sound Ingots.			
2	1¼	0·50	0·21	0·80	0·03	0·85	0·052	0·05/0·038 = 1·32
3	2	0·41	0·48	0·98	0·044	1·04	0·068	0·06/0·041 = 1·46
4	2¾	0·34	0·28	0·73	0·032	0·78	0·045	0·05/0·022 = 2·27
5	3	0·34	0·16	0·70	0·034	0·757	0·058	0·057/0·041 = 1·39
6	3	0·60	0·23	0·777	0·030	0·802	0·055	0·025/0·043 = 0·58
7	3½	0·40	0·12	0·79	0·027	0·97	0·064	0·18/0·064 = 2·81
8	8	0·39	0·08	0·98	0·016	1·06	0·031	0·08/0·026 = 3·68
10	10½	0·30	0·13	0·68	0·008	0·80	0·042	0·12/0·058 = 2·07
11	20	0·21	0·17	0·65	0·022	0·68	0·035	0·03/0·022 = 1·36
12	25	0·44	0·29	0·74	0·023	0·93	0·087	0·19/0·11 = 1·73
14	64	0·40	0·16	0·61	0·026	0·72	0·055	0·11/0·05 = 2·20
15	110	0·27	0·24	0·66	0·021	0·78	0·073	0·12/0·089 = 1·35
16	172	0·32	0·13	0·768	0·015	1·006	0·117	0·238/0·175 = 1·36
33	1¾	0·28	0·17	0·63	0·01	0·70	0·03	0·07/0·034 = 2·06
36	1½	0·40	0·21	0·81	0·04	0·89	0·072	0·08/0·055 = 1·45
38	1¾	0·41	0·18	0·62	0·045	0·68	0·094	0·06/0·084 = 0·72
39	1¾	0·37	0·25	0·63	0·034	0·70	0·066	0·07/0·055 = 1·27
40	1½	0·41	0·25	0·58	0·033	0·63	0·068	0·05/0·06 = 0·83
44	1¼	0·32	0·29	0·55	0·031	0·58	0·044	0·03/0·022 = 1·36
45	1¾	0·33	0·30	0·59	0·041	0·63	0·052	0·04/0·019 = 2·10
46	1¾	0·30	0·26	0·57	0·035	0·62	0·060	0·05/0·043 = 1·16
47	1¼	0·35	0·26	0·65	0·033	0·76	0·112	0·11/0·136 = 0·81
48	5¾	0·13	0·05	0·50	0·028	0·61	0·171	0·11/0·246 = 0·45
49	1¾	0·34	0·28	0·75	0·028	0·84	0·061	0·09/0·057 = 1·58
50	1¾	0·32	0·36	0·89	0·028	1·04	0·088	0·15/0·103 = 1·46
60	1	0·36	0·21	0·55	0·023	0·62	0·048	0·07/0·043 = 1·63
					Nearly Sound Ingots.			
32	1½	0·63	0·21	0·64	0·044	0·68	0·067	0·04/0·04 = 1·00
51	2¼	0·46	0·08	0·64	0·043	0·79	0·159	0·15/0·20 = 0·75
52	2¼	0·46	0·08	0·63	0·043	0·71	0·089	0·08/0·079 = 1·00
53	3¼	0·46	0·08	0·63	0·042	0·84	0·213	0·21/0·294 = 0·71
54	2¼	0·46	0·08	0·58	0·041	0·68	0·091	0·10/0·086 = 1·16
					Unsound Ingots.			
R 24	3	·0·06	0·012	0·37	0·025	0·38	0·124	0·01/0·17 = 0·06
25	6¾	0·10	0·012	0·496	0·036	0·611	0·286	0·115/0·43 = 0·27
26	7¼	0·14	0·024	0·568	0·030	0·59	0·072	0·022/0·072 = 0·30
27	6¾	0·13	0·02	0·458	0·024	0·488	0·108	0·03/0·144 = 0·21
28	8	0·15	...	0·50	0·048	0·65	0·29	0·15/0·416 = 0·36
29	3½	0·12	0·03	0·65	0·084	0·71	0·249	0·06/0·284 = 0·21
30	7¼	0·19	0·075	0·528	0·030	0·517	0·056	... 0
31	7½	0·13	...	0·484	0·028	0·490	0·041	0·006/0·022 = 0·27
41	1¾	0·41	0·10	0·50	0·045	0·57	0·148	0·07/0·177 = 0·39
42	1¾	0·37	0·08	0·37	0·057	0·40	0·204	0·03/0·253 = 0·12
43	1¾	0·33	0·08	0·60	0·042	0·62	0·076	0·02/0·058 = 0·34
55	3¼	0·08	...	0·41	0·026	0·40	0·054	... 0
56	3½	0·215	0·011	0·59	0·029	0·62	0·060	0·03/0·053 = 0·57
57	3½	0·22	0·02	0·56	0·03	0·62	0·076	0·06/0·079 = 0·76
58	3½	0·21	0·014	0·58	0·03	0·62	0·057	0·04/0·046 = 0·86
R 59	3½	0·05	...	0·52	0·072	0·52	0·106	... 0
R 61	2	0·08	...	0·39	0·046	0·38	0·109	... 0
R 62	6¾	0·02	...	0·03	0·033	0·02	0·106	... 0
R 63	4½	0·06	...	0·61	0·032	0·59	0·059	... 0
R 64	4½	0·06	...	0·63	0·029	0·59	0·072	... 0
R 65	2½	0·05	...	0·06	0·018	0·06	0·089	... 0

R = Rimming ingot.

NOTE.—Ingots Nos. 1, 9 and 13 are not included; No. 1 weighed less than 1 ton and sufficient data are not given in the case of Nos. 9 and 13.

these ratio groupings, for, excluding the rimming steels, the amounts of the segregating elements in all three classes of ingots are mostly similar, the chief exception being that a few of the unsound ingots are comparatively low in carbon. The question to be answered, therefore, is whether the liberation of carbon monoxide and hydrogen, aided by a low silicon content, brings about a displacement of the reaction $FeS + Mn \rightleftarrows MnS + Fe$ to the left. In this connection reference should here be made to the segregation in a 20-ton ingot which was described some years ago by Parsons and Duncan.[2] This ingot was 70 in. in dia. and 45 in. high, and was cast in a preheated mould placed on a chill bottom 6 ft. deep. A flame was applied within the covered top, which ensured that the ingot set gradually from the base upwards, so that the surface layer, where a heavy amount of segregate collected, was last to solidify. The liquid segregate was thus in contact with the burner gases for many hours, and, although the ingot was quite sound, the silicon content being 0·24%, the recorded analysis shows the increment $Mn/1·72S$ ratio to be only 0·19, so that in this respect the segregate behaved like that in unsound ingots. It will be indicated in the next section that in sound ingots the carbon, phosphorus and sulphur in segregating all tend to carry a higher proportion of manganese. In this respect also the Parsons ingot is an exception, for the increment ratio $Mn/(C + P + S)$ places it in line with the unsound ingots.

(2) While, broadly speaking, the sound ingots described by the Committee could be distinguished from unsound ones by the Mn/S ratios in the segregate increments, these ratios were by no means uniform in either class, as can be seen in Table I. This fact prompted the enquiry as to whether any relationship existed between the manganese increment and that of the carbon and phosphorus which, together with the sulphur relationship, might account for these variations. The method employed was to ascertain the maximum increment in the percentage of each element and then to plot the figures against the manganese increment between the same two points. This, of course, presented no difficulty in dealing with a single element, but, owing to the fact that the positions of maximum difference for the three elements do not always coincide, the manganese increments were occasionally not quite the same, and it was, therefore, necessary in examining the total segregation to arrive at as fair an average as possible from the recorded results. The amounts decided upon after a careful inspection of each set of analyses are stated in the last column of Tables II. and III. In the majority of instances the manganese increment given was that between the positions where the greatest carbon difference occurred (usually C and E, Fig. 1), since this element was found to have by far the most important influence; for the remainder, viz., sound ingots Nos. 5, 6, 7, 8, 15 and 16, and unsound ingots Nos. 25, 26, 27, 30, 31 and 57, an average value was taken, in estimating which adjacent manganese

TABLE II.—*Increments of Carbon, Phosphorus, Sulphur and Manganese in Sound Ingots.*

No.	Max. Carbon Increase.		Max. Phosphorus Increase.		Max. Sulphur Increase.		Total C, P, S Increase.	Manganese Increase.
	%.	Atomic %.	%.	Atomic %.	%.	Atomic %.	Atomic %.	%.
4	0·110	0·0092	0·016	0·00052	0·015	0·00047	0·0102	0·06
5	0·169	0·0141	0·022	0·0007	0·024	0·00075	0·0155	0·05
6	0·149	0·0124	0·023	0·00074	0·025	0·00078	0·0139	0·025
7	0·28	0·0233	0·042	0·00135	0·037	0·00116	0·0258	0·20
8	0·155	0·0129	0·008	0·00026	0·015	0·00047	0·0136	0·09
10	0·20	0·0167	0·006	0·0002	0·034	0·00107	0·018	0·12
11	0·09	0·0075	0·024	0·00077	0·016	0·0005	0·0088	0·03
12	0·41	0·0342	0·068	0·00219	0·064	0·002	0·0384	0·21
14	0·22	0·0183	0·028	0·0009	0·029	0·00091	0·0201	0·10
15	0·31	0·0258	0·039	0·00126	0·052	0·00163	0·0287	0·15
16	0·492	0·041	0·069	0·00223	0·102	0·00319	0·0464	0·25
33	0·19	0·0158	0·013	0·00042	0·02	0·00062	0·0168	0·08
34	0·09	0·0075	0·007	0·00023	0·004	0·0001	0·0078	0·06
35	0·09	0·0075	0·005	0·00016	0·004	0·0001	0·0078	0·06
36	0·15	0·0125	0·01	0·00032	0·032	0·001	0·0138	0·09
37	0·10	0·0083	0·006	0·0002	0·003	0·0001	0·0086	0·04
38	0·275	0·0229	0·016	0·00052	0·049	0·00153	0·0249	0·05
39	0·16	0·0133	0·014	0·00045	0·032	0·001	0·0147	0·07
40	0·15	0·0125	0·015	0·00048	0·035	0·00109	0·0141	0·07
44	0·13	0·0108	0·004	0·00013	0·013	0·00041	0·0113	0·03
45	0·04	0·0033	0·004	0·00013	0·011	0·00034	0·0038	0·04
46	0·11	0·0092	0·011	0·00036	0·025	0·00078	0·0103	0·06
47	0·22	0·0183	0·036	0·00116	0·079	0·00247	0·0219	0·11
48	0·18	0·015	0·035	0·00113	0·143	0·00447	0·0206	0·11
49	0·18	0·015	0·034	0·00109	0·033	0·00103	0·0171	0·10
50	0·21	0·0175	0·052	0·00168	0·060	0·00188	0·0211	0·15
60	0·16	0·0133	0·020	0·00065	0·025	0·00078	0·0147	0·07

NOTE.—Ingots Nos. 1, 2, 3, 9, 13 and 66 are omitted, Nos. 1 and 66 being less than 1 ton in weight, Nos. 2 and 3 owing to uncertainty as to the Mn content at position E, and Nos. 9 and 13 because the required analyses are not given.

TABLE III.—*Increments of Carbon, Phosphorus, Sulphur and Manganese in Unsound Ingots.*

No.	Max. Carbon Increase.		Max. Phosphorus Increase.		Max. Sulphur Increase.		Total C, P, S Increase.	Manganese Increase.
	%.	Atomic %.	%.	Atomic %.	%.	Atomic %.	Atomic %.	%.
25	0·30	0·025	0·153	0·0049	0·25	0·00781	0·038	0·12
26	0·131	0·0109	0·023	0·0007	0·042	0·0013	0·013	0·035
27	0·126	0·0105	0·033	0·0011	0·084	0·0026	0·014	0·04
28	0·37	0·0308	0·182	0·0059	0·242	0·0076	0·0445	0·16
29	0·21	0·0175	0·172	0·0055	0·165	0·0052	0·028	0·06
30	0·17	0·0142	0·027	0·0009	0·026	0·0008	0·016	0·02
31	0·07	0·0058	0·004	0·0001	0·013	0·0004	0·0065	0·02
32	0·29	0·0242	0·018	0·0006	0·023	0·0007	0·0255	0·05
41	0·30	0·025	0·041	0·0013	0·103	0·0032	0·0295	0·07
42	0·29	0·0242	0·044	0·0014	0·147	0·0046	0·030	0·03
43	0·10	0·0083	0·013	0·0004	0·034	0·0011	0·010	0·02
51	0·405	0·0338	0·076	0·0024	0·116	0·0036	0·040	0·15
52	0·25	0·0208	0·032	0·001	0·046	0·0014	0·023	0·08
53	0·55	0·0458	0·109	0·0035	0·171	0·0053	0·0545	0·21
54	0·41	0·0342	0·047	0·0015	0·05	0·0016	0·0375	0·10
55	0·04	0·0033	0·015	0·0005	0·028	0·0009	0·0045	0·01
56	0·125	0·0104	0·021	0·0007	0·031	0·001	0·012	0·03
57	0·13	0·0108	0·031	0·001	0·046	0·0014	0·013	0·055
58	0·06	0·005	0·016	0·0005	0·027	0·0008	0·0065	0·04

NOTE.—Rimming steels are not included, their manganese increments being for the most part negligible. Ingot No. 68 is also omitted since it was less than 1 ton in weight,

percentages were sometimes included. It should be observed, however, that these adjustments were comparatively insignificant in their effect, for when the widest manganese differences along or near the axes were used instead, the results were virtually the same;
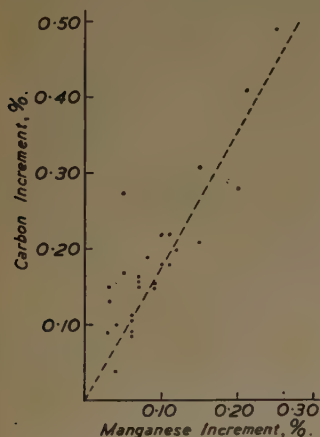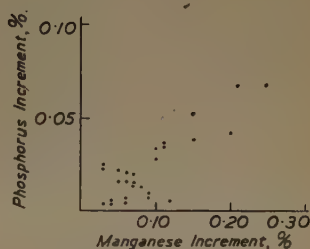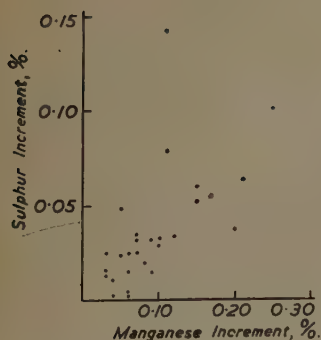

FIG. 2.—Sound Ingots.

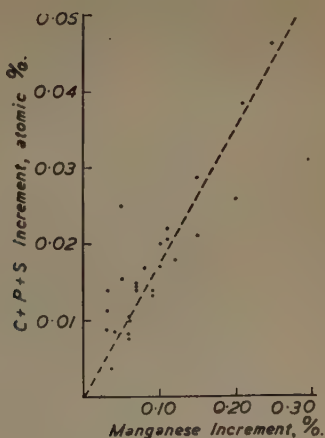FIG. 3.—Sound Ingots.

FIG. 4.—Sound Ingots.

FIG. 5.—Sound Ingots.

the averaging method was adopted because it seemed to be less open to criticism.

The graphs obtained on plotting separately the percentage increments of carbon, phosphorus and sulphur against those of manganese in the sound ingots are shown respectively in Figs. 2, 3

and 4. In all three instances a fairly linear relationship is revealed, that for carbon being the most satisfactory, for only one point is not reasonably close. According to the cast history this ingot, No. 38, was purposely cast on the cold side. The sulphur print shows that it contained a very localised area of rich segregate in the head, but, except for that, the macrostructure appears to be quite normal. These individual relationships having been disclosed, the further step was then taken of plotting the total atomic percentage increments against the weight percentage increases of manganese. The result is seen in Fig. 5, and a comparison with Fig. 2 will show that, while the two graphs are very similar, the points in Fig. 5 are on the whole a little closer together. It may thus be inferred that all three elements in segregating carry a small
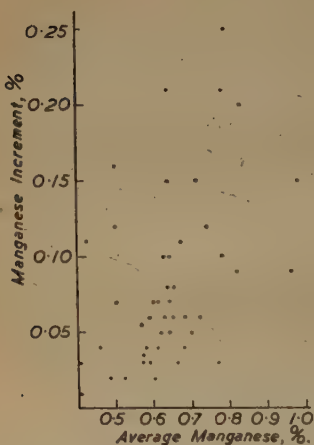
FIG. 6.—Sound and Unsound Ingots.   FIG. 7.—Unsound Ingots.
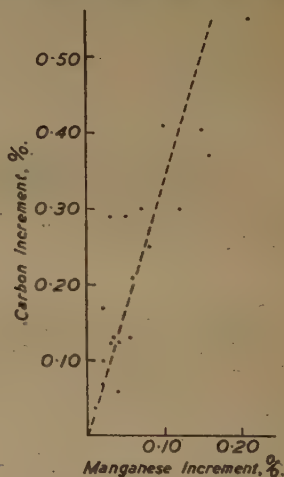
excess of manganese, carbon taking the predominant amount. The only apparent alternative to this conclusion is that the manganese increments are simply due to the segregation of manganese *per se*, but of this no evidence could be found; for when these increments in both sound and unsound ingots were plotted against the average manganese contents of the steels the points were very scattered, as shown in Fig. 6.

Turning now to the unsound ingots, on plotting separately the percentage increases of carbon, phosphorus and sulphur with those of manganese there was again an indication of a linear relationship in each instance, as shown in Figs. 7, 8 and 9. Again, too, the carbon curve was the most satisfactory, although definitely less so than the curve obtained when the total atomic percentages were plotted against the weight percentages of manganese, as seen in

Fig. 10.   These graphs demonstrate more plainly than those for the
sound ingots that the three elements carbon, phosphorus and sulphur
all contribute a quota to the total manganese increment, that due
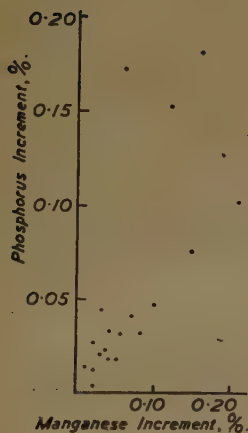to the carbon being predominant in both classes.   Now since the
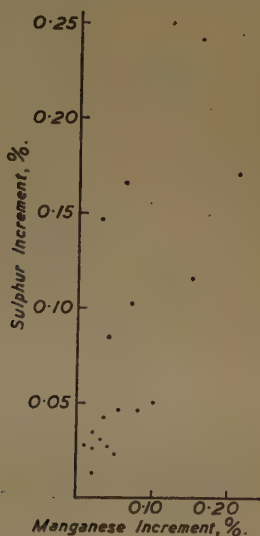

FIG. 8.—Unsound Ingots.

FIG. 9.—Unsound Ingots.

evidence clearly points to a direct
proportionality, it may be concluded
that the three metalloids were partly
combined with the manganese in the
liquid steel.   If that be the case, the
further inference may be drawn that
these elements were also combined
with iron, and most probably to a
much greater extent, considering its
relative mass preponderance.   In fact,
the argument can be carried still
further, for if the carbon, phosphorus
and sulphur exist largely as com-
pounds of iron and manganese at the
freezing point, it is reasonable to
assume they will remain in that state
after   solidification.   Consequently
carbon should be present as carbide
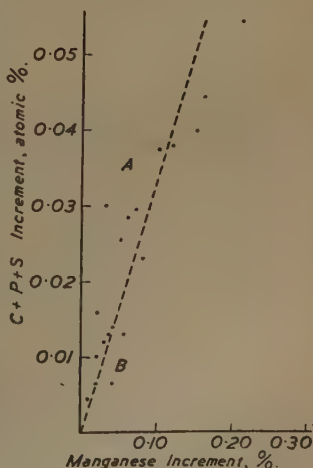in both austenite and martensite, a

FIG. 10.—Unsound Ingots.

view which is contrary to that held by many metallurgists.
It may here be mentioned that the same conclusion was reached
by the author during an investigation of the Eggertz test for
combined carbon,[3] for the reactions which take place between
the nitric acid and the carbon were found to be essentially the same
whether the steel had been quenched, tempered, normalised or an-
nealed. Variations in the depth and shade of the solution colours
obtained when a steel in the above conditions is dissolved were
explained as due simply to differences in the magnitude and shape
of the carbide particles.

Before proceeding to the next item, there are two things to be
noted in connection with Fig. 10. The first is that the curve there
plotted has a steeper gradient than the corresponding curve for the
sound ingots in Fig. 5. This means, of course, that in unsound
ingots less excess of manganese is associated with a given segregate
increment, and it should be observed that the same conclusion can
be drawn from the Mn/S ratios in Table I. The second thing to be
noted is that the points in the graph occur in two distinct groups, as
indicated by the letters A and B. Since no obvious explanation was
apparent, it seemed worth while to enquire whether the ingots in one
group had some feature in common which was not present in those
of the other. An examination was therefore made of their sulphur
prints and the cast histories, special attention being given to the
unsoundness of the ingots as revealed by their macrostructures.
The data which seemed to be relevant are recorded in Table IV.

TABLE IV.—*Unkilled Steels; Condition of Metal and Ingots.*

Ingot No.	Group A.	Ingot No.	Group B.
25	Boiler plate steel.	26	Cast hotter than No. 25.
28	" Quiet " steel.	27	" Wilder " than No. 26.
29	Nearly sound free-cutting steel.	30	Enough gas evolved to cause the top to rise.
32	Slightly gassy.	31	A deep pipe cavity.
41	Moderately gassy.	43	Cast rather " wild."
42	,, ,,	55	0·08% carbon, most probably gassy.
51	Slightly gassy.	56	Same as No. 30.
52	,, ,,	57	A considerable pipe cavity.
53	,, ,,	58	Same as No. 57.
54	,, ,,		

Surveying this information as a whole, the impression was gained
that the ingots in group A had evolved less gas while freezing than
those in group B, or, in other words, that the richest segregates
occurred when but little gas was liberated during solidification.

In favour of this supposition is the fact that if the rimming steels had been included, they would all have appeared in group B.

(3) From the data given in Table II. indications of another relation between manganese and segregation can be derived. It was shown recently by the author [4] that, when the maximum sulphur increments along the axes were divided into the differences between the manganese contents at the same two positions, the ratios obtained were approximately proportional to those of manganese to sulphur at position E in both sound and unsound ingots. This was taken to mean that the proportion of sulphur existing as MnS as the metal solidified depended upon the Mn/S ratio in the steel. Now, since the other two segregating elements also seemed to be associated with manganese, it was clear that only part of the ground had been covered; in the case of carbon particularly a similar relationship might hold. A further examination in this direction was accordingly made. First, the ratios of manganese to carbon in the segregate increments of the sound ingots (Table II.) were calculated, and on plotting these against the ratios of manganese to carbon in the steel at the position of maximum segregation (see Table V.) the result

TABLE V.—*Analyses at Maximum Axial Concentrations in Sound Ingots (Positions* D, E *or* H).

No.	Carbon. %.	Carbon. Atomic %.	Phosphorus. %.	Phosphorus. Atomic %.	Sulphur. %.	Sulphur. Atomic %.	Total C, P, S. Atomic %.	Manganese. %.	Ratio of Mn, %, to O + P + S, atomic %.	Increment Ratio of Mn, %, to O + P + S, atomic %.
4	0·40	0·0333	0·050	0·0016	0·045	0·0014	0·0365	0·78	21·4	5·88
5	0·458	0·0382	0·055	0·0018	0·058	0·0018	0·042	0·742	17·7	3·23
6	0·681	0·0567	0·060	0·0019	0·055	0·0017	0·0605	0·802	13·25	2·16
7	0·63	0·0525	0·074	0·0024	0·064	0·002	0·057	0·97	17·0	7·75
8	0·47	0·0392	0·031	0·001	0·031	0·001	0·041	1·06	25·85	6·62
10	0·42	0·035	0·015	0·0005	0·042	0·0013	0·037	0·80	21·6	6·7
11	0·25	0·0208	0·051	0·0016	0·035	0·0011	0·0235	0·68	28·9	3·41
12	0·75	0·0625	0·094	0·003	0·087	0·0027	0·068	0·93	13·7	5·47
14	0·53	0·0442	0·053	0·0017	0·055	0·0017	0·0475	0·72	15·2	4·97
15	0·46	0·0383	0·063	0·002	0·073	0·0023	0·0425	0·781	18·4	5·23
16	0·675	0·0562	0·091	0·0029	0·117	0·0037	0·063	1·006	15·95	5·39
33	0·42	0·035	0·028	0·0009	0·030	0·0009	0·037	0·70	18·9	4·76
34	0·35	0·0292	0·023	0·0007	0·012	0·0004	0·0305	0·69	22·6	7·69
35	0·38	0·0317	0·019	0·0006	0·011	0·0003	0·0325	0·69	21·25	7·69
36	0·49	0·0408	0·024	0·0008	0·072	0·0023	0·044	0·89	20·02	6·52
37	0·51	0·0425	0·019	0·0006	0·010	0·0003	0·0435	0·71	16·3	4·65
38	0·615	0·0512	0·042	0·0014	0·094	0·0029	0·0555	0·68	12·25	2·00
39	0·50	0·0417	0·038	0·0012	0·066	0·0021	0·045	0·70	15·55	4·76
40	0·51	0·0425	0·040	0·0013	0·068	0·0021	0·046	0·63	13·7	4·96
44	0·42	0·035	0·030	0·0009	0·044	0·0014	0·0375	0·58	15·45	2·65
45	0·36	0·030	0·026	0·0008	0·052	0·0016	0·0325	0·63	19·4	10·05
46	0·39	0·0325	0·037	0·0012	0·060	0·0019	0·0355	0·62	17·45	5·82
47	0·53	0·0442	0·062	0·002	0·112	0·0035	0·0495	0·76	15·35	5·02
48	0·26	0·0217	0·049	0·0016	0·171	0·0053	0·0285	0·61	21·4	5·34
49	0·49	0·0408	0·071	0·0023	0·061	0·0019	0·045	0·84	18·65	5·85
50	0·49	0·0408	0·088	0·0028	0·088	0·0028	0·0465	1·04	22·35	7·11
60	0·48	0·040	0·046	0·0015	0·048	0·0015	0·043	0·62	14·4	4·76

shown in Fig. 11 was obtained. Then, the corresponding ratios for the total atomic percentages of carbon, phosphorus and sulphur were found—the figures for which are given in the last two columns of Table V.—and on plotting these a similar, but slightly better, relationship was revealed, as shown in Fig. 12. In both these graphs the same two marked deviations from the general trend of the points occur. The lower one, on abscissa 28·9 of Fig. 12, is that of ingot No. 11, but of this outstanding exception no explanation can be suggested. The higher one, on abscissa 19·4, belongs to ingot No. 45, and it is perhaps significant that this is the only example in which titanium was used as a deoxidiser, 0·1% having been added.
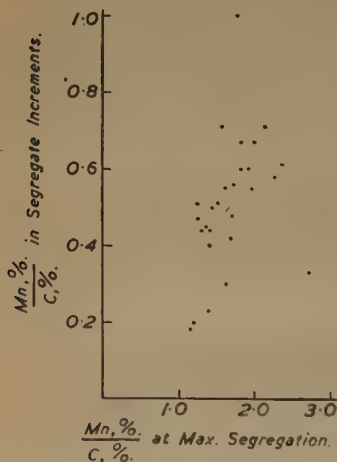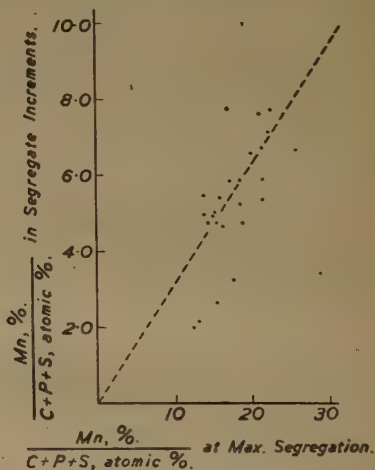
Fig. 11.—Sound Ingots.   Fig. 12.—Sound Ingots.

Unlike the sound ingots, the unsound gave but little indication of any such relationship, although it held fairly well with the sulphur. Here again, therefore, the disturbance due to the liberation of gases may have had an influence.

(4) The Sixth Report of the Committee contains an investigation of seven manganese steel blooms which were cut so as to include the top discard of the ingots [1e] (loc. cit., p. 27). In each instance there was a complete absence of segregation; in fact, the phosphorus contents at position E actually tended to be a shade lower than in the adjacent zones nearer the skin. Apparently, therefore, segregation had been entirely prevented by the addition of 12 to 14% of manganese. Hence, it seemed not unlikely that a retarding effect of manganese in the ordinary steels might be discoverable, provided that the following conditions needed for an equitable assessment of the degree of segregation could be met :

(1) The ingots to be compared should be of equal size, or nearly so, and should have been cooled at approximately the same rate.

(2) The ingots should be quite sound, since gas evolution undoubtedly facilitates the movement of segregate.

(3) The steels should not contain appreciable quantities of other alloying elements, including titanium, likely to combine with the carbon, phosphorus or sulphur.

Unfortunately these restrictions greatly reduced the number of ingots available for the enquiry, for only the fourteen stated in Table VI. were found to comply. Having selected these ingots as suitable, a method of estimating the liability of the steel to segregate had then to be found, and, after some consideration, it was decided to take the widest differences between the analyses along the axis as a gauge. Here, however, a difficulty was encountered in that position E, where the maximum segregation always occurred, was unreliable for this purpose, since the increments would there depend to an unknown extent upon the weight of metal in the head and also upon the place where the drillings happened to be taken. There was thus no alternative but to use instead position H, it being far less open to these objections. The increments in the percentages of carbon, phosphorus and sulphur at this position in each ingot over that where the lowest concentration occurred, either position B or C, were then found and, after these had been converted into atomic percentages, their total was divided by the sum of the average atomic percentages of the same elements in the steel. The ratios thus obtained are given in the last column of Table VI. and were regarded as the indices of the degree of segregation; the left half of Table VI. contains the increments used in calculating these ratios (II.).

To ascertain whether segregation diminished as the manganese content increased, it was then necessary to find the ratios of the amounts of manganese to the total atomic percentages of carbon, phosphorus and sulphur in the steels. Now, since either the pit sample analysis or that at position A could be considered as representative of the actual composition, to arrive at this the two sets of analyses were compared, and, when any appreciable variation occurred, an average value (A) was taken; in the few cases where no pit sample results are recorded, those at position A were, of course, used. The figures selected, together with the ratios (I.) derived from them, are given in the right half of Table VI. These ratios are probably not quite valid, owing to valency differences; for instance, the carbon atom may have been combined with three atoms of manganese and the sulphur atom with only one. Since, however, carbon is by far the preponderating element, an error due to that cause should be negligible. Finally, having found the ratios I. and II. in Table VI., they were plotted as shown in Fig. 13. The points

TABLE VI.—*Method of Calculating Ratios I. and II. plotted in Fig. 13.*

	Increment at Position H over Position B (or C).							Average Cast Analyses.								I. Ratio of Mn, %, to Average C + P + S, atomic %.	II. Ratio of C + P + S Increment, atomic %, to Average C + P + S, atomic %.
Ingot No.	Carbon.		Phosphorus.		Sulphur.		Total C + P + S. Atomic %.	Carbon.		Phosphorus.		Sulphur.		Total C + P + S. Atomic %.	Manganese. %		
	%.	Atomic %.	%.	Atomic %.	%.	Atomic %.		%.	Atomic %.	%.	Atomic %.	%.	Atomic %.				
3	0·05	0·0042	0·01	0·0003	0·012	0·0004	0·0049	0·43(A)	0·0358	0·057(A)	0·0018	0·056	0·0018	0·0394	1·03(A)	26·1	0·124
4	0·06	0·005	0·013	0·0004	0·01	0·0003	0·0057	0·37(A)	0·0308	0·043	0·0014	0·04	0·0013	0·0335	0·75(A)	22·4	0·170
33	0·04	0·0033	0·003	0·0001	0·004	0·0001	0·0035	0·28	0·0233	0·018(A)	0·0006	0·012	0·0004	0·0243	0·65	26·7	0·144
34	0·05	0·0042	0·004	0·0001	0·001	...	0·0043	0·28(A)	0·0233	0·019(A)	0·0006	0·010	0·0003	0·0242	0·64(A)	26·4	0·178
35	0·08	0·0067	0·005	0·0002	0·002	...	0·0069	0·34	0·0283	0·013	0·0004	0·009	0·0003	0·029	0·66(A)	22·8	0·238
36	0·07	0·0058	0·006	0·0002	0·012	0·0004	0·0064	0·40	0·0333	0·018(A)	0·0006	0·054	0·0017	0·0356	0·83(A)	23·3	0·18
37	0·10	0·0083	0·006	0·0002	0·03	0·0001	0·0086	0·44(A)	0·0367	0·02	0·0006	0·01(A)	0·0003	0·0376	0·70(A)	18·6	0·229
38	0·275	0·0229	0·016	0·0005	0·046	0·0014	0·0248	0·41	0·0342	0·029	0·0009	0·055	0·0017	0·0368	0·63(A)	17·1	0·674
39	0·15	0·0125	0·013	0·0004	0·030	0·0009	0·0138	0·38(A)	0·0317	0·027(A)	0·0009	0·042(A)	0·0013	0·0339	0·64	18·9	0·407
40	0·08	0·0067	0·005	0·0002	0·020	0·0006	0·0075	0·41	0·0342	0·03	0·001	0·046(A)	0·0014	0·0366	0·60(A)	16·4	0·205
44	0·13	0·0108	0·004	0·0001	0·013	0·0004	0·0113	0·32	0·0267	0·028	0·0009	0·038	0·0012	0·0288	0·57	19·8	0·392
46	0·06	0·005	0·006	0·0002	0·014	0·0004	0·0056	0·30	0·025	0·028	0·0009	0·042	0·0013	0·0272	0·58	21·3	0·206
49	0·04	0·0033	0·003	0·0001	0·005	0·0002	0·0036	0·34	0·0283	0·042(A)	0·0014	0·030(A)	0·0009	0·0306	0·78	25·4	0·118
50	0·04	0·0033	0·006	0·0002	0·006	0·0002	0·0037	0·32	0·0267	0·039(A)	0·0013	0·032(A)	0·001	0·029	0·91(A)	31·4	0·128

(A) = Result at position A or else an average figure.

form a reasonably good curve, which, moreover, approaches the zero ordinate in the manner required by the fact that manganese steels do not segregate. It may, therefore, be tentatively concluded that the degree of segregation is reduced as the ratio of the manganese content to the atomic percentages of carbon, phosphorus and sulphur in the steel increases, and this leads to the further inference that it is chiefly the compounds of these elements with iron which give rise to the type of major heterogeneity common to ingots of more than about one ton in weight.
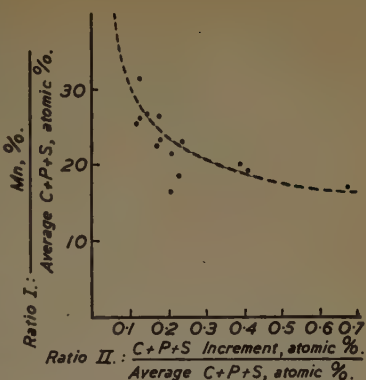
FIG. 13.—Ratios I. and II. in Table VI. plotted.

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DISCUSSION.

Dr. W. H. HATFIELD, F.R.S. (Vice-President; Brown-Firth Research Laboratories, Sheffield), Chairman of the Committee on the Heterogeneity of Steel Ingots, who opened the discussion, said that the paper was of a kind to which the Ingot Committee looked forward. He did not think it was generally appreciated that for something like eighteen years the Ingot Committee, with the full resources of the iron and steel industry behind them, had been making a study of ingots, and they had probably cut up £100,000 worth of ingots. That might be a surprising statement, but he thought that the work had been well worth while.

Over those years, as time had passed, they had learned to examine those ingots with a greater degree of exactitude; they had become more meticulous as time passed, and the result was that of late years the data obtained from the ingots examined had been presented in, probably, a more discriminating and more accurate manner than in the earlier days. He felt that the author, in going through this large mass of data, had been under the disadvantage, which could not be dissociated from the nature of the work, that the validity of the data that he had been studying had not been uniform. As time passed, the work of the Ingot Committee had been more worthy of detailed discrimination and examination.

It had for a long time been an anomaly to those who regarded segregation—manganese sulphide, for instance—as likely to result in a geometrical relationship of the manganese and sulphur, that that relationship did not exist, and they were very much indebted to the author for the critical examination which he had made. He stated that in the blown ingots the relationship of the manganese to the sulphur was different from that which existed in the solid ingots. Personally, he would submit to the author that the blown ingots were, on the average, very much lower in carbon than the solid ingots.

Mr. WHITELEY : Not all of them.

Dr. HATFIELD, continuing, said that if that was so, the segregation of carbon became less, and the carrying of the manganese carbide along with the manganese sulphide would not be as effective. That was probably the explanation of the little difference which the author observed.

The work which the author had done on this one part of the researches of the Committee was, as he himself had said, typical of the work which the Committee would like to have done. They had examined a large number of ingots and had collected a vast accumulation of data. They met at least seven or eight times a year, and at each meeting the most interesting discussions took place,

arising out of which further experimental ingots were put on one side, or asked for, for examination. In that way, as in other branches of study and learning, they accumulated such a mass of data that it was beyond the possibility of a single mind to survey it all and draw accurate and helpful deductions, so that they were much indebted to the author for this paper.

There was one suggestion which he would like to make. The Council, on going into the position of the Andrew Carnegie Research Fund that morning, had found that that fund was in an excellent condition, simply because, owing to the exigencies of the moment, there were not those applicants for Carnegie Scholarships who would normally have presented themselves. It might be a good idea, therefore, if one or two applications for Carnegie Scholarships were submitted by young men who were sufficiently interested in this intriguing subject to devote a whole year, or two years, to studying some aspect of the vast accumulation of data derived from the researches of the Ingot Committee. Many Members of the Committee were so fully occupied with current events and current problems that, while they could give all the support necessary and see that the resources and means of investigation were available, they had not the time adequately to consider what they had created, so that he thought it would be a good plan if, among the younger men who were coming forward, two or three could be found who would interest themselves in this work with a view to following the course set by Mr. Whiteley, taking some interesting problem and, out of the great mass of data available, attempting to see what valid deductions could be drawn.

The Committee had worked on the heterogeneity of steel ingots for eighteen years, and, frankly, he felt that it would be another eighty years before the problem was brought to anything like the solution which was essential.

Dr. S. A. MAIN (Messrs. Hadfields, Ltd., Sheffield) said that the author would probably agree that the research described in the paper was very dependent on the figures and on the way in which those figures were obtained. While the method employed by the author was probably sufficiently accurate to establish his main conclusions, the speaker thought that, in view of the value of this mathematical method as one means of finding out the nature of the segregates, the use of a more accurate method was well worth while for what further information it would give.

When the author's paper came along he, the speaker, recalled an effort he himself had made in the same direction in the early days of the Ingot Committee. He had been able to turn up some diagrams which he had then made and bring them to the Meeting. In these diagrams the four segregating elements, manganese, carbon, phosphorus and sulphur, had been plotted against each other in pairs, thus involving six comparisons.

It was apparent that the relation for any of the pairs of elements was not a hard and fast one even inside an individual ingot. Nevertheless, there was some sort of average relationship, which could be obtained mathematically.

If only two individual points were taken to determine the coefficient of increase of one element in relation to another, it was obviously a matter of chance whether the figure so derived represented the true average relationship, and it might be very badly in error. The great care which the author had given to the selection of the two points was not an adequate safeguard against this. He, the speaker, was inclined to attribute some of the anomalies found by the author to this cause. Those anomalies did not, however, militate seriously against the broad distinction found between sound and unsound ingots.

The mathematical method of determining the true average relationship was not difficult, but was rather lengthy when applied to the large number of ingots concerned—still, as mentioned, he thought it well worth while if someone had the time available.

Using an approximation, he had found the average atomic relationship between manganese, carbon, phosphorus and sulphur for the particular ingot concerned in the diagrams that he had shown, which happened to be ingot No. 7.   This relationship was $1 \cdot 98 : 17 \cdot 95 : 1 \cdot 0 : 1 \cdot 0$ in the order named or, to the nearest integers, $2 : 18 : 1 : 1$.   For another ingot of the same class, namely, of killed steel, the figures were $3 \cdot 15 : 13 \cdot 7 : 0 \cdot 67 : 1 \cdot 0$ or, approximately, $9 : 41 : 2 : 3$.   In both of these cases an unknown quantity of iron atoms must naturally be added, as iron undoubtedly entered into the constitution of the segregate.   Thus, the atomic relationship was by no means constant whether inside an individual ingot or between different ingots.

Everything pointed to the segregate being a complex or conglomerate rather than a chemical compound.   A compound of these four elements with iron would indeed be in the nature of an unholy alliance.   That was not to say that the segregate did not contain binary compounds such as manganese sulphide or carbide of iron, or even ternary compounds.   The work of Andrew and his colleagues, using quite independent methods, had also pointed strongly to the segregate being in the nature of a complex of these elements.

When the best possible figures were obtained, the real difficulty was to draw correct conclusions, and he did not think the author had quite made his point that each of the metalloids was combined with manganese.

Mr. WHITELEY : Partly combined.

Dr. MAIN, continuing, said that the author, in drawing these conclusions, had relied on the numerical relationships between the elements being fixed numbers, but they were not fixed and they

varied even inside the same ingot. That was important, because the author went on to derive further inferences about the state of the elements in the fluid steel just before freezing, and of the carbon in austenite and martensite.

In those cases which the speaker had examined the nearest to fixed proportions was shown between the sulphur and the phosphorus, yet it was difficult to imagine what compound there could be involving those two elements.

Each and all of the three elements, carbon, sulphur and phosphorus, was not therefore necessarily combined, the speaker thought, with the manganese.

It seemed possible that the operation of the physical processes of separation might bring out the separate elements or their compounds in roughly similar proportions at the same time, the proportions being modified by local deficiencies or surpluses of one or the other element.

Dr. C. H. DESCH, F.R.S. (Vice-President; Iron and Steel Industrial Research Council), said that the Institute was very much indebted to the author for his very careful analysis of the figures obtained. Whatever the explanation of the facts might be, the data which the author had collected and presented in the form of diagrams would have to be taken into account, and that there was a relation of the kind that the author proposed was shown clearly by such diagrams as Fig. 5 and Fig. 12.

He did not agree, however, that this was any evidence of the existence of compounds in solution. From a physico-chemical point of view, it was likely that compounds would be dissociated, and that the quantity of molecules in solution would be very small in proportion to the free atoms, and on solidification he thought that the same thing applied, at any rate for several of the elements. The position of carbon in austenite, for example, was quite well known; there was no carbide present, and it was known that the carbon atoms were distributed at random in the interstitial spaces. With regard to martensite, the position was different; he had maintained for a long time that in martensite there were cementite molecules present, and that fitted in with the author's previous work on the action of nitric acid.

With regard to sulphur, the author had shown some years ago that at high temperatures iron sulphide was the stable substance, and as the temperature fell that went over progressively into manganese sulphide. To explain these facts, it was not necessary to assume compound formation at the high temperatures; it was enough to use the ordinary principles of differential freezing, but to apply them quantitatively was difficult, because some of the ternary diagrams were not known with sufficient accuracy. At the same time, the fact that these elements tended to segregate together was quite clear.

One element had been left out of consideration, and that was oxygen. In some of these ingots there was a good deal of oxygen, and the peculiar anomaly mentioned in the case of the Parsons ingot might be, he thought, in part accounted for by the accumulation in the upper layer of the iron sulphide-oxide eutectic, which was not taken into account but which did seem to appear in some of the photomicrographs. That would perhaps account for the peculiar ratio of manganese to the other elements which was found there.

As he had said, anyone who wished in future to explain segregation would have to make very great use of the diagrams which the author had prepared with such great care.

CORRESPONDENCE.

Dr. D. BINNIE (The Lancashire Steel Corporation, Ltd., Irlam, near Manchester) wrote that, of the four segregating elements in a plain carbon steel, viz., carbon, sulphur, phosphorus and manganese, Mr. Whiteley had shown that manganese alone behaved erratically. He had used different methods of presenting this erratic behaviour, as in Table I., where the ratio of the increment in manganese to the sulphur, estimated atomically, was utilised as an index of the peculiar behaviour of manganese, and again in his graphs in Fig. 5 and Fig. 10, where the manganese segregation increment was shown to be greater for sound ingots than for unsound ones.

Mr. Whiteley was inclined to believe that carbon, sulphur and phosphorus might carry some excess of manganese in segregating and inferred that all three elements existed largely as components of iron and manganese in liquid steel. Consider first of all the silicon contents of the ingots in Table I. If the silicon content was plotted against the ratio in the last column the points on the curve fell naturally into three groups, his sound ingots, nearly sound ingots and unsound ingots; or, again, taking an average silicon content of the ingots in Table I. :

	Silicon.
Sound ingots	0·23%
Nearly sound ingots	0·10%
Unsound ingots	0·04%

figures which indicated that the deoxidiser silicon had a control in determining his group classification and incidentally in the erratic behaviour of manganese.

A clue could perhaps be found from the study of a rimming-steel ingot, since rimming steel represented the best example of a non-solid or unsound steel. Mr. Whiteley had noticed that his index ratio in Table I. was very low for rimming steels and in four of his examples a minus figure was obtained.

In the study at Irlam of a rimming-steel ingot—an experimental

ingot allowed to freeze with little or no stabilising addition of aluminium—the data recorded in Table A were obtained, data which had shown that the manganese segregation in a rimmed-steel ingot was of a small or negative order.   On passing up the axis of

TABLE A.—*A Rimmed-Steel Ingot Analysed at the Standard Positions along the Axis* (see *Fig. 1 of the paper*).

Ingot Position.	Carbon. %.	Sulphur. %.	Phosphorus. %.	Manganese. %.
C .	0·030	0·050	0·014	0·26
D .	0·040	0·063	0·022	0·27
H .	0·060	0·148	0·031	0·29
E .	0·070	0·238	0·055	0·29
Heavy segregate near position E .	...	0·514	...	0·27

the ingot, carbon, sulphur and phosphorus had segregated, manganese had not segregated very much, and at positions just off the axis the manganese segregation was actually negative.   However, immediately above position E, where segregation was most intense, a pool of scum had collected, a scum which analysed :

		Another Example.
Ferrous oxide .	30·3%	35·07%
Ferric oxide .	6·0%	7·57%
Manganous oxide .	57·3%	51·6%
Silica .	2·9%	2·8%
Lime .	Nil	Nil
Phosphorus .	0·05%.	0·044%
Sulphur .	...	0·23%

Manganese had been thrown out of solution in an oxide complex, which floated and collected in a recess near to the top of the ingot.   The cause of the lack of segregation of manganese as metal could readily be explained by the separation of the manganese in oxide form.   If the manganese had not been oxidised it would have segregated in the steel more closely in keeping with the segregation of carbon, sulphur and phosphorus.

The throwing-out of manganese in oxide form was discussed in the paper by Hultgren and Phragmen [1] in the section which dealt with the influence of manganese, sulphur and phosphorus on rimming steel.   An extract from their paper read : " It should be remembered, when the diagram Fig. 2 (of that paper) is used for the discussion of the solidification of alloys containing manganese, that the manganese content of the liquid will increase a little, owing to selective solidification and, when the oxygen solubility surface is reached, it will decrease again on account of the relatively high manganese content of the oxide phase separating from the liquid."

[1] *Jernkontorets Annaler*, 1938, vol. 122, No. 8, p. 377.

Progressive additions of a deoxidiser such as silicon progressively stopped the oxidation of manganese, and in fully killed steels a segregation of manganese could be expected to occur.   Manganese of itself probably did reduce segregation, but the homogeneity of the 12% and 14% manganese steels, mentioned in the fourth part of the paper, could hardly be used in support of this view, since, when manganese became the predominating element in the steel, the liquidus-solidus range would become narrow, an effect which lost its importance when the manganese varied between 0·5% and 1% or so, as it did in the ingots in Mr. Whiteley's Table VI.

AUTHOR'S REPLY.

Mr. WHITELEY, in a written reply, said that he fully agreed with Dr. Hatfield that the data contained in the published work of the Ingot Committee should yield additional information if systematically studied, but whoever took that in hand would need to start with some object in view such as Dr. Main had indicated.   The various aspects of heterogeneity in steel ingots still provided much scope for investigation.   Dr. Hatfield had suggested that since the carbon in blown ingots was generally lower than that in sound ingots the segregation of carbon in them should be less.   But that was by no means so, as could be seen from the fact that the average carbon increment in the unsound ingots of Table III. was 0·227% as against 0·186% in the sound ingots of Table II.   Moreover, eight of the unsound ingots were medium-carbon steels and the points for five of them lay on the left side of the curve in Fig. 10.   The curves in Figs. 5 and 10 plainly showed that a given increment of carbon, phosphorus and sulphur carried less manganese with it in unsound than in sound ingots, irrespective of the degree of carbon segregation.

Dr. Main was evidently not quite sure in his own mind as to the accuracy of the method that he (Mr. Whiteley) had used, in which maximum differences along the axis had alone been considered. He had chosen that plan of attack because it appeared to him to be the most expedient for the enquiry.   While examining the data he had not neglected lesser differences, but, since they showed the same trend, the very large amount of additional work involved in treating them in the same way seemed scarcely worth doing. As far as he could see, the implications were that small proportions of the carbon, sulphur and phosphorus in the increments were combined with manganese as separate compounds and not as a single one, as Dr. Main had apparently understood.   He (Mr. Whiteley) had to admit that when making the statement on p. 71 P " it may be concluded that the three metalloids were partly combined with the manganese in the liquid steel," it did not occur to him to insert the word " each " after " were " so as to avoid any possibility of a complex compound being inferred.   He regretted that he could not

altogether follow Dr. Main's description of his alternative mathe-matical method and wished he had been more explicit. Presumably Dr. Main regarded it as a better way to compare the degree of segregation of any one element with that of another at various places in each ingot, thus taking the elements as pairs. If so, the fact should not be overlooked that, during the passage through the critical range, carbon tended to leave areas rich in phosphorus; also the movement of those two elements as solidification proceeded might be more consistent than that of the sulphur, since there was a likelihood that some of the sulphide was precipitated before freezing began. He (Mr. Whiteley) would point out that the method that he had adopted avoided any discrepancies due to such causes.

In reply to Dr. Desch's remarks he would first say that, previous to making the investigation described in the paper, he had almost taken it for granted that carbon and phosphorus, at any rate, existed as free elements in the liquid steel. The results, therefore, surprised him, because they indicated some degree of combination, and he was now inclined to the opinion that dissociation diminished as the freezing point was approached. Some further support for that view could be adduced from the heat effect which followed silicon additions. Körber and Oelsen [1] had affirmed that when silicon dissolved in molten iron much heat was evolved, and recently at an open-hearth conference it was stated that a pronounced rise in temperature was recorded with the new immersion thermo-couple when solid ferro-silicon was added to steel in the ladle. The inference was, therefore, that a considerable amount of iron silicide was formed, and if that was the case it was not at all unlikely that carbon and phosphorus could also exist in a state of combination.

Both Dr. Desch and Dr. Binnie referred to oxygen as a factor in segregation. The requisite data not being available, however, he (Mr. Whiteley) had been unable to include this element in his analysis. He had simply stated that, with a given increment of carbon, phosphorus and sulphur, the degree of manganese segregation was reduced when gases were evolved and left it at that, although he had, of course, recognised that the oxygen present as FeO or MnO was chiefly responsible for the gas liberation. With regard to the Parson's ingot, he could not find any convincing evidence that oxygen had been picked up in an appreciable quantity as Dr. Desch seemed to suggest. If that had occurred some oxidation of both the silicon and manganese should have taken place, and since there was ample time for much of the oxide so formed to coalesce and rise to the surface as scum, the percentage of those elements should have been lowered in the upper layer; yet their contents in that region were actually slightly higher than elsewhere. Nor were the illus-trations any more informative in that direction. He thought the

nearest approach to a eutectic formation was to be seen in Fig. 21, taken at a position midway between the centre and outside of the ingot, and there the arrangement of the particles seemed to resemble the eutectiform grouping of MnS described by Portevin and Castro [1] rather than the iron-oxide sulphide eutectic mentioned by Dr. Desch.

He was quite unable to agree with Dr. Binnie that silicon had a controlling influence in the erratic behaviour of manganese, for when the ratios for the sound ingots given in the last column of Table I. were plotted against the silicon contents there was no indication of any relationship between the two; the points were, in fact, as widely scattered as those in Fig. 6. As further evidence that silicon was of no importance he had set out in Table B eight of the sound ingots in the order of an increasing silicon percentage; again no correspondence was to be seen between either the total metalloid or manganese increments and the amounts of silicon present in the steels.

TABLE B.—*Eight Sound Ingots arranged in Order of Increasing Silicon Content.*

Ingot No.	Silicon. %.	Total Carbon, Phosphorus and Sulphur Increase. Atomic-%.	Manganese Increase. %.
48	0·05	0·0206	0·11
8	0·08	0·0136	0·09
7	0·12	0·0258	0·20
11	0·17	0·0088	0·03
36	0·21	0·0138	0·09
46	0·26	0·0103	0·06
45	0·30	0·0038	0·04
50	0·36	0·0211	0·15

Dr. Binnie gave an interesting example of heavy segregation in the core of a rimming-steel ingot, but his explanation of the lack of a manganese increment as being due to the loss of manganese in the scum was without support and was therefore an assumption. It seemed quite as reasonable to infer that much of the scum came from the rimmed portion of the ingot, since there was usually far less non-metallic matter in that zone than in the core. Moreover, even in ingots of killed steel, scums rich in MnO sometimes appeared on the surface. Having fixed his mind on silicon, however, Dr. Binnie then proceeded to state that " progressive additions of a deoxidiser such as silicon progressively stopped the oxidation of manganese, and in fully killed steels a segregation of manganese could be expected to occur." In reply, he (Mr. Whiteley) would point out that a manganese increment was not confined to sound ingots; indeed, five of the increments in the unsound ingots of

[1] *Journal of the Iron and Steel Institute,* 1935, No. II., p. 207.

Table III. were greater than the average, 0·09, for the sound ingots in Table II.

Dr. Binnie also stated that when manganese was the predominating element in the steel, the liquidus-solidus range would become narrow, for which reason he presumably inferred that segregation would be diminished. He (Mr. Whiteley) had never seen the complete equilibrium diagram of the iron-manganese-carbon system and was rather surprised to learn that the liquidus-solidus range was narrow when about 1·3% of carbon was present. In any case, he was not prepared to admit, on present evidence, that the major segregation in steel with which the paper was concerned was the result of differential solidification.
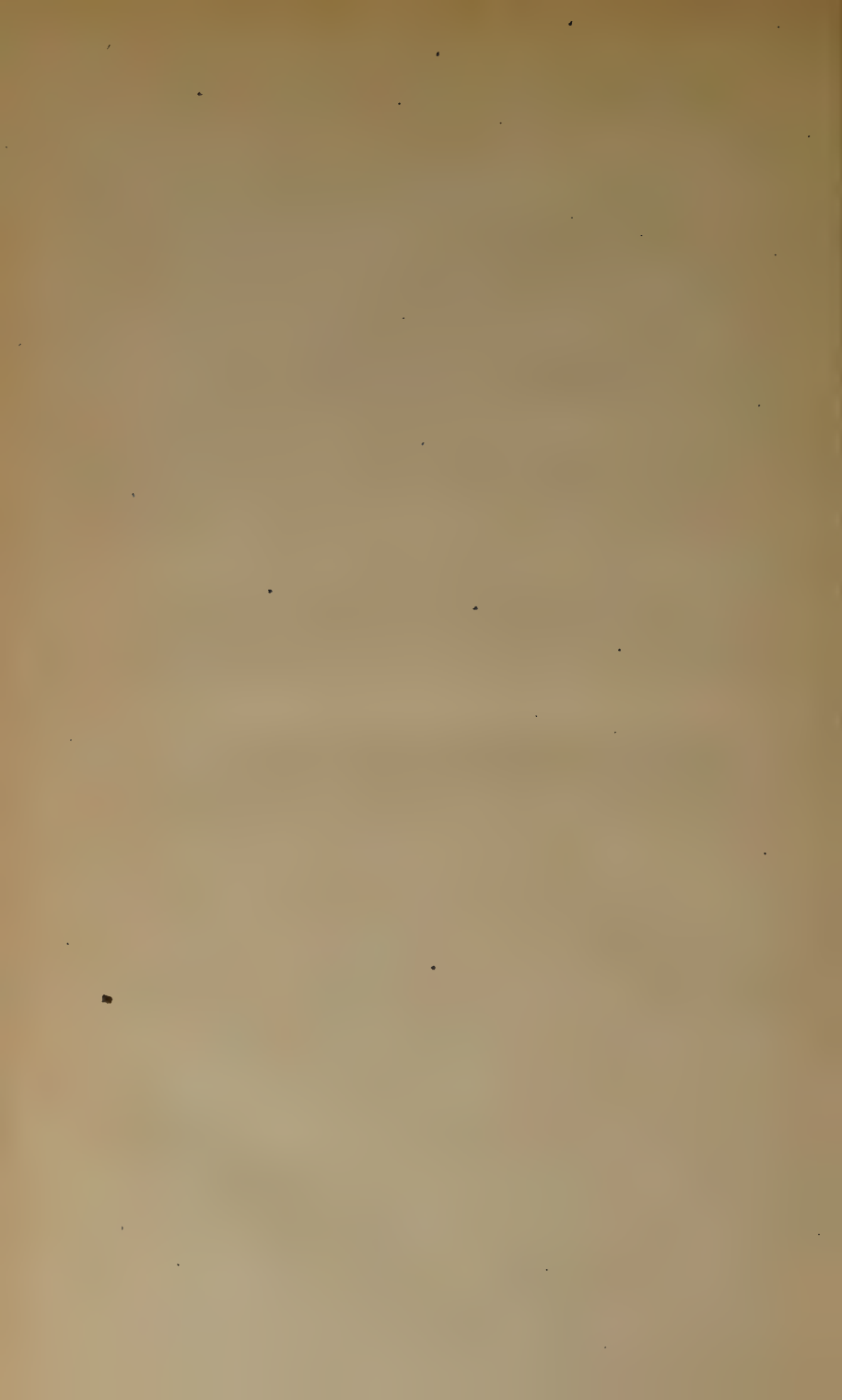
A STUDY OF SOME OF THE FACTORS AFFECTING THE RESISTANCE OF CAST IRON TO DEFLECTION UNDER LOAD AT HIGH TEMPERATURES.[1]

By L. W. BOLTON, A.M.I.MECH.E. (BRITISH CAST IRON RESEARCH ASSOCIATION, BIRMINGHAM).

(Figs. 11 to 38 = Plates IX. to XIV.)

SYNOPSIS.

A study has been made of some of the factors affecting the resistance of cast iron to deflection at high temperatures. A method of testing was developed in which a bar of standard dimensions was rigidly held at one end, while the other end was loaded, the stressed portion of the bar being held at a constant temperature of 850° C. The deflection of the free end of the bar was recorded and measured.

The effect of composition was studied and it was found that both silicon and phosphorus increased the resistance of cast irons to deflection at 850° C. Graphite size was found to have an important influence on the results obtained, and in the case of irons of similar composition, those having coarse graphite flakes will deflect more rapidly than those in which the graphite is in a finer state of division.

Three plain carbon steels were tested for comparison, and it was found that the rigidity of these steels at 850° C. was less than that of many of the cast irons tested.

An examination was also made of the rigidity of two types of austenitic cast iron. These were found to have a good resistance to deflection at the temperature of the tests. The rigidity of these austenitic irons was increased by additions of chromium.

Introduction.

ORDINARY grey cast iron fails at high temperature through growth and scaling, but special irons have been developed in recent years which possess resistance to a marked extent to both these effects. The extended application of these irons in industry has made it desirable to have some information regarding their resistance to deformation under prolonged application of light loads at high temperatures.

The work described in this report was carried out with a view to supplying some of this information, and since the results of quantitative creep tests at high temperatures are extremely difficult to interpret for purposes of design, it was felt that the work should not be confined to actual creep tests on the special irons, but rather should be designed with a view to studying the influence of com-

position, structure and casting conditions on this phenomenon. In this way it was hoped to obtain data on the relative resistance to deformation under load at high temperatures of various types of heat-resisting cast irons which are now available.

Most heat-resisting cast irons have a fine graphite structure, and some owe their qualities to the presence of an abnormally high silicon content (*i.e.*, more than 4·5%). Others are austenitic, and consequently are far less rigid at room temperature than pearlitic or ferritic irons. It is sometimes desirable that the irons contain a moderate quantity of phosphorus in order to improve the castability of the metal. For these reasons, special attention has been given in this work to the influence of graphite size, variations in silicon and phosphorus contents, and to alloying employed to the extent of rendering the structure of the iron austenitic. Some data on carbon steels of varying carbon content have also been obtained.

For the purpose of this exploratory work, a method of testing has been developed which consists essentially of transverse-loading a bar of standard dimensions at one end, while the other end is rigidly held, the stressed portion of the bar being held at a predetermined constant temperature. Details of the apparatus used and the method of carrying out the test are described below.

After consideration of the various industrial applications in which cast iron is used at high temperatures, it was decided that information was most needed on its resistance to deformation at between 800° C. and 900° C. A temperature of 850° C. was therefore chosen for the investigation.

Apparatus Used and Method Employed in the Test.

The layout of the apparatus used is shown in Fig. 1. The specimen (*D*) is a bar 7 in. long and 0·6 in. in dia., reduced to 0·5 in. in dia. for a distance of 1 in. near one end, for the purpose of
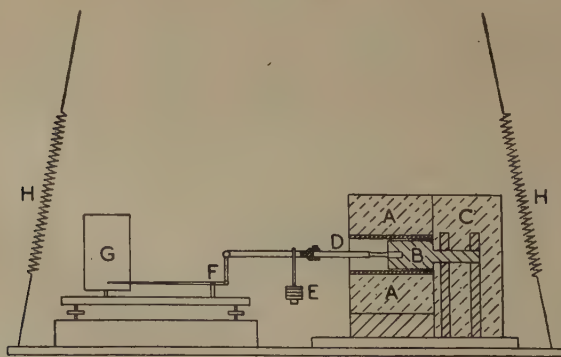
FIG. 1.—Apparatus for Examining the Rigidity of Cast Iron at Elevated Temperatures.

localising the stress.   One end of the bar is rigidly held in a heavy heat-resisting nickel-chromium-alloy holder (B), clamped to the base of the apparatus by means of stout cast-iron brackets.   The test-piece is loaded at the free end with weights (E), and a system of levers (F) amplifies the movement of the pointer at the end in the ratio of 10 to 1, this movement (*i.e.*, deflection at the free end) being recorded on a moving drum (G).   In order to eliminate the effects of vibration, the whole apparatus is suspended on springs (H). The test-piece is raised to, and maintained at, the required temperature by means of a resistance furnace (A), well lagged with kieselguhr.   On account of the massive size of the holder (B) the rest of the apparatus was also thoroughly insulated with kieselguhr and slag wool (C).   The temperature of the specimen was obtained by means of a platinum/platinum-10%-rhodium thermocouple the hot junction of which could be moved along the bar for a distance of 1 in.   The furnace temperature was not thermostatically controlled, but the variations in temperature did not exceed $\pm 7°$ C. and these variations were found to be without effect on the manner in which the bars deflected under load.

In carrying out the test, the furnace was slowly raised to the required temperature, and a steady temperature state was reached in approximately 5 hr. from the time of switching on the furnace. During this heating-up period, the test bar was supported at the free end to prevent any sagging under its own weight.   The weights used at the free end were such that the transverse stress at the narrowed part of the bar near the fixed end could be increased in steps of 0·1 ton per sq. in. from 0 to 2 tons per sq. in.

The effect of applying a load at the free end of the bar was to cause a fairly rapid rate of deflection for the first 3 or 4 hr., but after this the rate of deflection gradually decreased and then remained constant.   At the end of a 24-hr. period, the load was stepped up by an increment of 0·1 ton per sq. in., which was maintained for another 24 hr., and this process was repeated until the bar had bent through an angle of approximately 10°.   It is worthy of note that even the most brittle of cast irons, such as the high-silicon and high-phosphorus irons, were found to deform to this extent at 850° C. without breaking.

The tests carried out showed that the section of the bar as-cast had a considerable influence on the manner in which the test-piece was deformed under load at high temperatures.   It was found, for instance, that test-pieces machined from thick cast sections were less rigid than those machined from thin sections of the same iron, and, in interpreting the results, this factor has to be taken into consideration.

The Influence of Silicon on the Rigidity of Cast Iron at 850° C.

The ordinary common grey iron of medium silicon content, often used at high temperatures, usually fails ultimately from

scaling and growth. Norbury and Morgan [1] have shown that if the graphite can be kept in a fine state of division, high-silicon cast irons have resistance to scaling and also a marked resistance to failure from growth. Such irons, having a silicon content of approximately 5%, together with a fine graphite structure, are known as Silal. The influence of additions of silicon to cast iron is well known, the matrix becoming harder and more brittle with increasing silicon. The eutectic carbon content is reduced and the high-silicon cast irons with a silicon content of 14% to 16%, used at present mainly for their resistance to chemical attack, contain usually less than 1·0% of total carbon, even when melted in contact with carbon, i.e., in the cupola.

A series (A) of bars with increasing silicon contents, ranging from 2% to 14%, was tested, the actual compositions being given in

TABLE I.—*Compositions of Irons, Series* A (*Increasing Silicon Contents*).

No.	T.C. %.	Si. %.	Mn. %.	S. %.	P. %.
1	3·10	1·98	1·16	0·034	0·022
2	3·33	3·28	0·75	0·019	0·067
3	2·15	6·62	1·19	0·028	0·034
4	2·67	7·16	1·17	0·031	0·031
5	1·63	9·32	1·19	0·011	0·100
6	1·07	13·77	1·09	0·014	0·125

Table I., and the results of the tests are plotted in Fig. 2. The cast size of the bars was 0·65 in. dia.

All the bars were cast in green-sand moulds from metal melted in a coke-fired crucible furnace. The crucible charges were made up from mixtures of Swedish white iron (3·8% total carbon), Armco iron, ferro-silicon (10% silicon) and ferro-manganese (80% manganese), to yield the desired composition. After the charge had melted down, the metal was superheated for approximately 15 min. and then skimmed and poured.

It will be seen from the curves in Fig. 2 that silicon exerts a stiffening influence on cast iron at the temperature of the tests. The microstructures of the bars are shown in Figs. 11 to 16. The iron containing 6·62% of silicon is of the Silal type and contains graphite in a finely divided state, as will be seen from the structure (Fig. 13). The graphite flakes in the 13·77% silicon iron are also small, but those in the other two high-silicon irons are relatively coarse. This fact will be examined later in the section on graphite size. Fig. 3 shows deflections plotted against silicon contents at a

[1] A. L. Norbury and E. Morgan, *Journal of the Iron and Steel Institute,* 1931, No. I., p. 413.
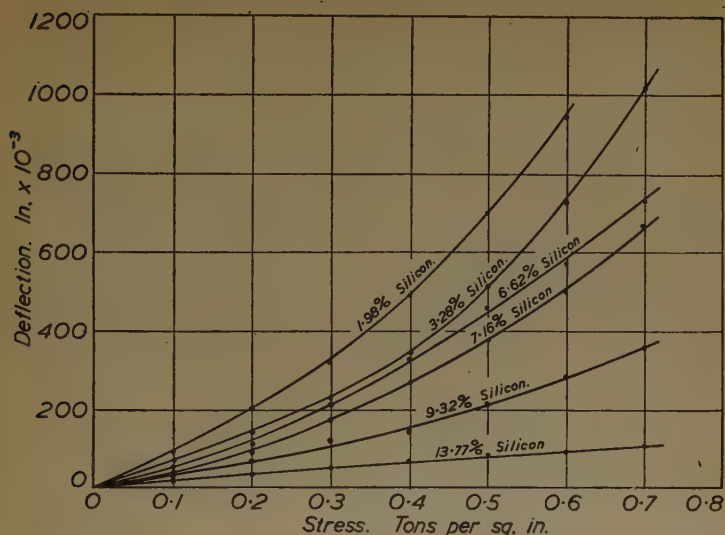
Fig. 2.—Deflection of Series *A* Bars at 850° C.
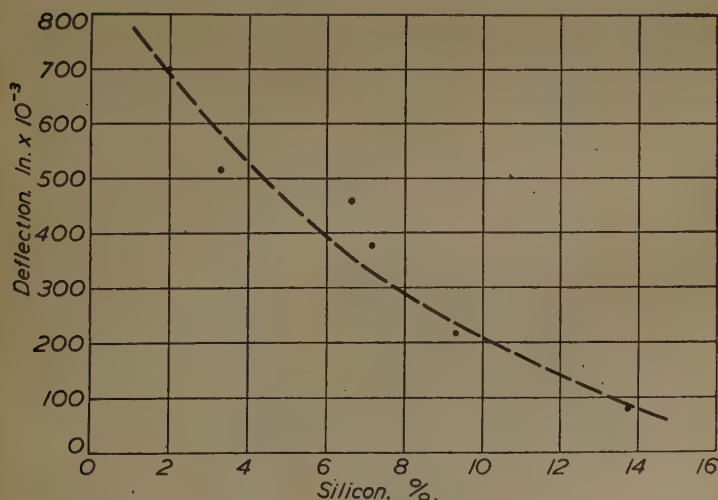
Fig. 3.—Deflection of Series *A* Bars after 5 days with total stress of 0·5 to per sq. in. at 850° C.

load of 0·5 ton per sq. in., *i.e.*, total deflection at the end of the fifth day of the test in each case. This shows clearly the increase in the rigidity of the irons as the silicon content is increased.

Air was able to enter the furnace during the tests, and this led to some scaling and growth, especially in the case of the low-silicon irons. Wastage of the specimens through scaling may be a contributory cause of the lack of rigidity of the two low-silicon irons. It will be noted from Fig. 2 that the deflection of the iron containing 3·28% of silicon was only slightly greater in the early stages of the test than that of the specimen which contained 6·62% of silicon. The sudden falling-off in the rigidity in the case of the lower-silicon bar as the test proceeded and as the load increased may be explained partly by this deterioration of the metal under heat. The scaling of the Silal bar was only superficial, as was also that of the other high-silicon irons. An interesting point is that these high-silicon irons, which, as already mentioned, are extremely brittle in the cold, were found to bend under prolonged stress at 850° C. The bar containing 13·77% of silicon gave a permanent deflection of 0·86 in. at the free end of the test-piece under a stress of 1·7 tons per sq. in. after twelve days at this temperature. (The stress was increased at the rate of 0·2 ton per sq. in. every 24 hr. after 0·7 ton per sq. in. had been reached.)

The results of these tests show that additions of silicon of the order of 7% and more considerably increase the resistance of cast iron to deformation under load at high temperatures.

The Influence of Phosphorus on the Rigidity of Cast Iron at 850° C.

In examining the influence of phosphorus, a base cast iron containing 5·5% of silicon was used, as this material scaled only slightly and had a very small growth. In this series (B) of bars tested, the phosphorus content varied between 0·4% and 1·1%. The as-cast size of the bars in this case was 0·875 in. in dia.

The bars were produced from a mixture of mild-steel scrap, refined pig iron and ferro-silicon (10% silicon), melted in a coke-fired crucible furnace. Additions of ferro-phosphorus (20% phosphorus) were made to the molten metal in the crucible before each bar was cast, the metal being returned to the furnace after each addition to bring it back to a suitable temperature for casting. The bars were cast in green-sand moulds, and the pouring temperature was kept as possible throughout the series.

The analyses of the bars used are given in Table II., and their microstructures are shown in Figs. 17 to 20.

TABLE II.—*Compositions of Irons, Series* B (*Increasing Phosphorus Contents*).

No.	T.C. %.	Si. %.	Mn. %.	S. %.	P. %.
7	2·40	5·59	1·20	0·035	0·377
8	2·47	5·50	1·17	0·043	0·639
9	2·42	5·42	1·14	0·039	0·927
10	2·41	5·42	1·13	0·040	1·100

Fig. 4 shows the deflections of these irons under stress at 850° C.
It will be seen that additions of phosphorus progressively increase
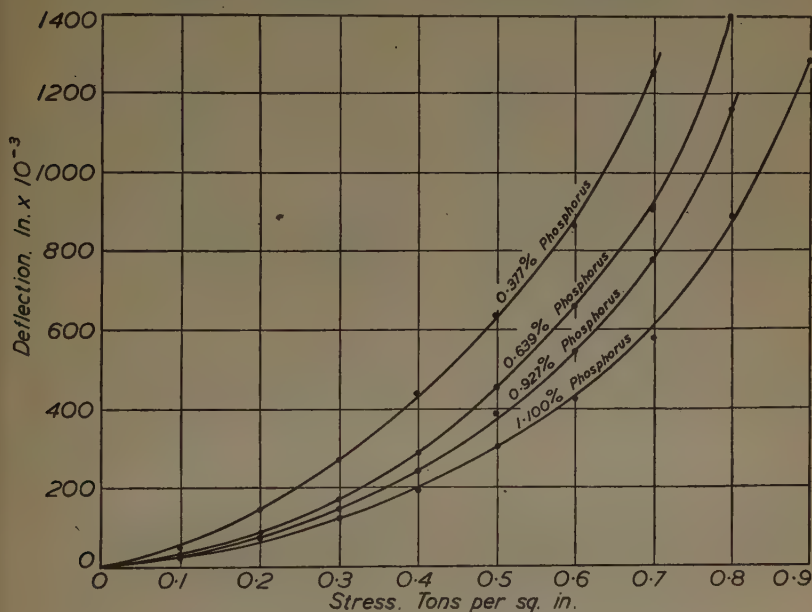
FIG. 4.—Deflection of Series *B* Bars at 850° C.
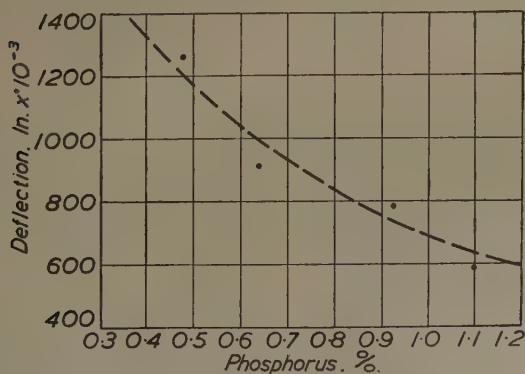
FIG. 5.—Deflection of Series *B* Bars after 7 days with
total stress of 0·7 ton per sq. in. at 850° C.

the stiffness of the metal at high temperatures. This stiffening
influence is clearly shown in Fig. 5, where deflections are plotted

against phosphorus contents for a stress of 0·7 ton per sq. in., *i.e.*, total deflection of the specimen at the end of the seventh day of the test in each case.   With the exception of the phosphorus content, the analyses of the bars are very similar, and it will also be seen that the microstructures are very much alike.   All the bars scaled only superficially, so that it would appear that the differences in rigidity are entirely due to the differences in phosphorus content. It should be noted, however, that the graphite size of the specimen containing 1·100% of phosphorus, the most rigid under test, is slightly coarser than that of the other bars in this series.

In order to examine the influence of phosphorus on cast iron of lower silicon content than Series *B*, two ordinary grey-iron bars (Nos. 11*A* and 12*A*) containing approximately 3·2% silicon, but with widely differing phosphorus contents, were tested (Series *C*).   The as-cast size of the bars was 0·65 in. in dia.   They were produced under similar conditions to the bars in Series *A*, and an addition of ferro-phosphorus (20% phosphorus) was made in the case of bar 12*A*.

The analyses are shown in Table III., and the results obtained are plotted in Fig. 6 (two lower curves).

It will be seen that the higher-phosphorus bar is more rigid than the one with low phosphorus, although the difference in rigidity in this case is less marked than would be expected from the results obtained in Series *B*.   Both bars in Series *C*, however, scaled on the surface and suffered from growth, and it is likely that this to some extent masked the influence of the differences in phosphorus content.   The tests on bars of Series *B* and *C* do, however, show that additions of phosphorus increase the resistance of cast iron to deflection at 850° C. over the range of silicon contents of the metal, 3·18–5·5%.

The Influence of Graphite Size on the Rigidity of Cast Iron at 850° C.

In order to examine the influence of graphite size, bars were cast in two different sizes from four different compositions.   In each case the bar cast to the larger original diameter contained graphite in larger flakes than the small-cast-diameter bar.

The metal was melted in a coke-fired crucible furnace and cast into green-sand moulds.   Each pair of bars, of large and small diameter, was cast from the same crucible of molten metal.   The components of the charges were the same as those employed in Series *A*, with an addition of ferro-phosphorus in the case of the charge from which bars 12*A* and 12*B* were cast.   The pouring temperature and moulding conditions were very similar for each pair of bars, and as far as possible were kept uniform throughout the series.   The differences in structure in the two different sizes of bar of the same composition are due to the influence of the section on the rate of cooling.

The microstructures of the bars, constituting Series *D*, are

PLATE IX.

Fig. 11.—Silicon 1·98%.

Fig. 12.—Silicon 3·28%.
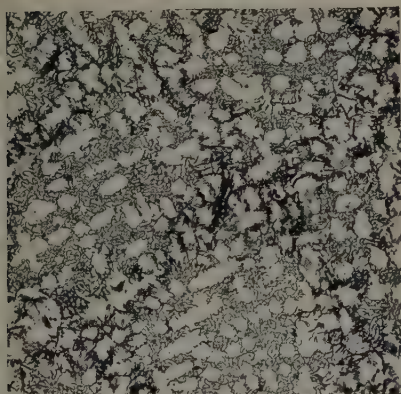
Fig. 13.—Silicon 6·62%.
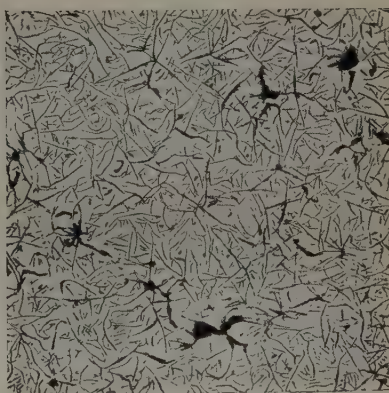
Fig. 14.—Silicon 7·16%.

Figs. 11 to 14.—Etched in Picric Acid.

Fig. 15.—Silicon 9·32%.

Fig. 16.—Silicon 13·77%.

Figs. 15 and 16.—Etched in 40% Hydrofluoric Acid, 20% Nitric Acid in Glycerine.

Figs. 11 to 16.—Increasing Silicon, Series *A*, 0·65-in. dia. bars. × 75.

PLATE X.

FIG. 17.—Phosphorus 0·377%.

FIG. 18.—Phosphorus 0·639%.

FIG. 19.—Phosphorus 0·927%.
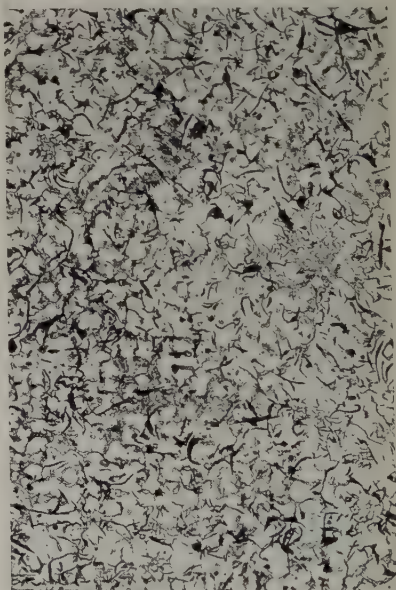
FIG. 20.—Phosphorus 1·100%.

FIGS. 17 to 20.—Increasing Phosphorus Series *B* (silicon 5·5%), 0·875-in. dia. bars. Etched in picric acid. × 75.

Bolton.

PLATE XI.

FIG. 21.—0·65-in. Dia. Bar.
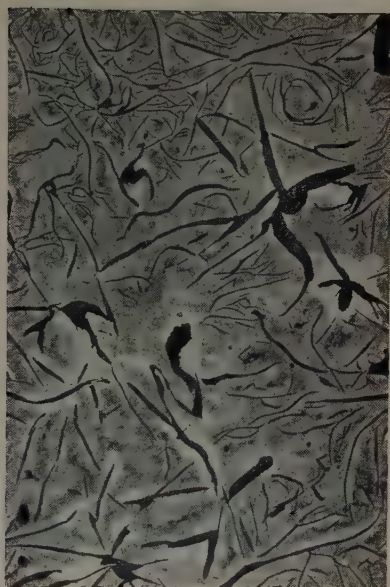
FIG. 22.—1·75-in. Dia. Bar.

FIGS. 21 and 22.—Phosphorus 0·067%, Silicon 3·28%.

FIG. 23.—0·65-in. Dia. Bar.
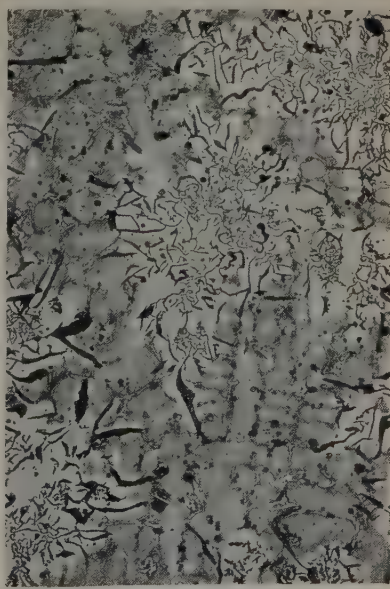
FIG. 24.—1·75-in. Dia. Bar.

FIGS. 23 and 24.—Phosphorus 1·320%, Silicon 3·18%.

FIGS. 21 to 24.—Small- and Large-Diameter Bars with Different Phosphorus Contents, Series *D*. Etched in picric acid. × 75.

[*Bolton.*

PLATE XII.
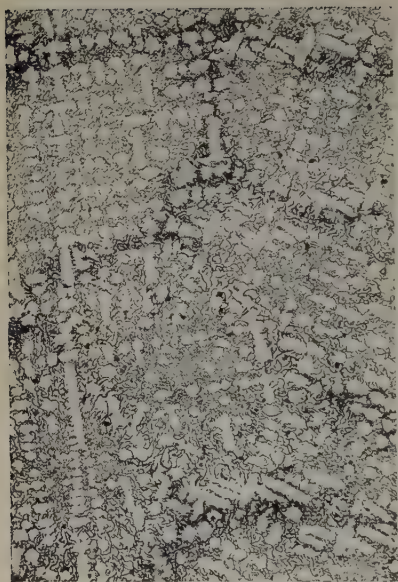
FIG. 25.—0·65-in. Dia. Bar.

FIG. 26.—1·2-in. Dia. Bar.

FIGS. 25 and 26.—Silicon 5·75%.

FIG. 27.—0·65-in. Dia. Bar.

FIG. 28.—1·2-in. Dia. Bar.

FIGS. 27 and 28.—Silicon 7·16%.

FIGS. 25 to 28.—Small- and Large-Diameter Bars with Different Silicon Contents, Series *D*.
Etched in picric acid. × 75.

[*Bolton.*

PLATE XIII.
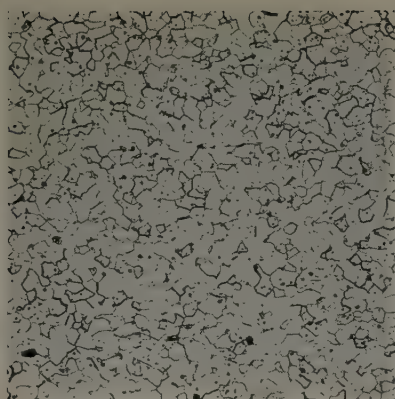
FIG. 29.—As Received.
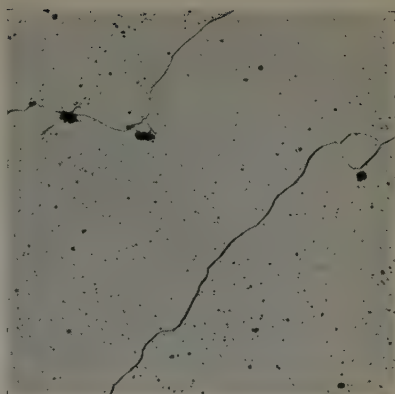
FIG. 30.—After Test.

FIGS. 29 and 30.—Carbon 0.02%.

FIG. 31.—As Received.
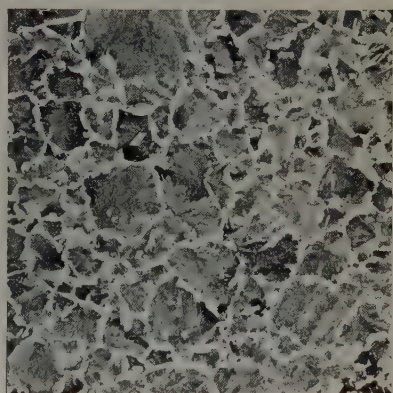
FIG. 32.—After Test.

FIGS. 31 and 32.—Carbon 0.46%.
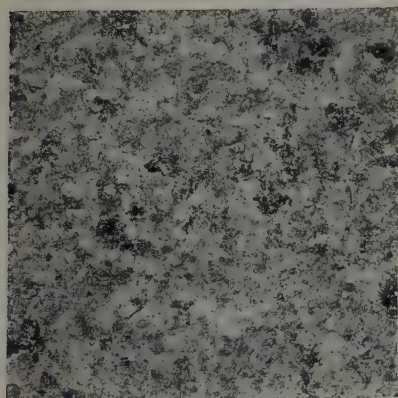
FIG. 33.—As Received.
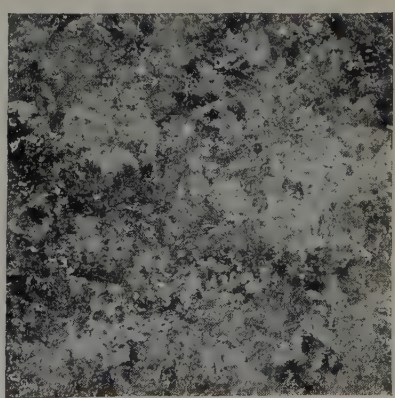
FIG. 34.—After Test.

FIGS. 33 and 34.—Carbon 0.84%.

FIGS. 29 to 34.—Steel Bars, Series *E*. Etched in picric acid. × 75.

[*Bolton.*

PLATE XIV.
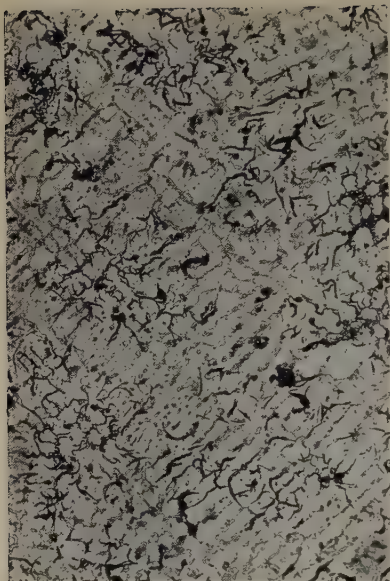
FIG. 35.—Copper 7·35%, Nickel 16·40%, Chromium 2·51%.

FIG. 36.—Silicon 5·90%, Nickel 17·15%, Chromium 1·95%.
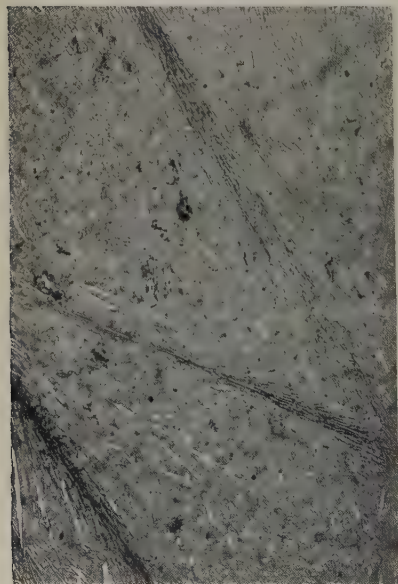
FIG. 37.—Copper 7·10%, Nickel 15·74%, Chromium 11·95%.

FIG. 38.—Silicon 4·91%, Nickel 18·65%, Chromium 7·25%.

FIGS. 35 to 38.—Alloy Heat-Resisting Irons, Series F, 0·75-in. dia. bars. Etched in 10% alcoholic hydrochloric acid (boiling). × 75.

shown in Figs. 21 to 28 and their actual analyses are given in Table III.

TABLE III.—*Compositions of Irons, Series* D *(Small- and Large-Diameter Bars).*

No.	Cast Diameter. In.	T.C. %.	Si. %.	Mn. %.	S. %.	P. %.
11*A* * 11*B*	0·65 1·75	3·33	3·28	0·75	0·019	0·067
12*A* * 12*B*	0·65 1·75	3·18	3·18	0·84	0·040	1·320
13*A* 13*B*	0·65 1·20	2·53	5·75	1·06	0·048	0·036
14*A* 14*B*	0·65 1·20	2·67	7·16	1·17	0·031	0·031

* Bars 11*A* and 12*A* constitute also Series *C*, high and low phosphorus contents.

Specimens for testing at 850° C. were turned from these bars. The results obtained on bars 11*A* and 11*B* and 12*A* and 12*B* are plotted in Fig. 6. These bars have similar carbon and silicon
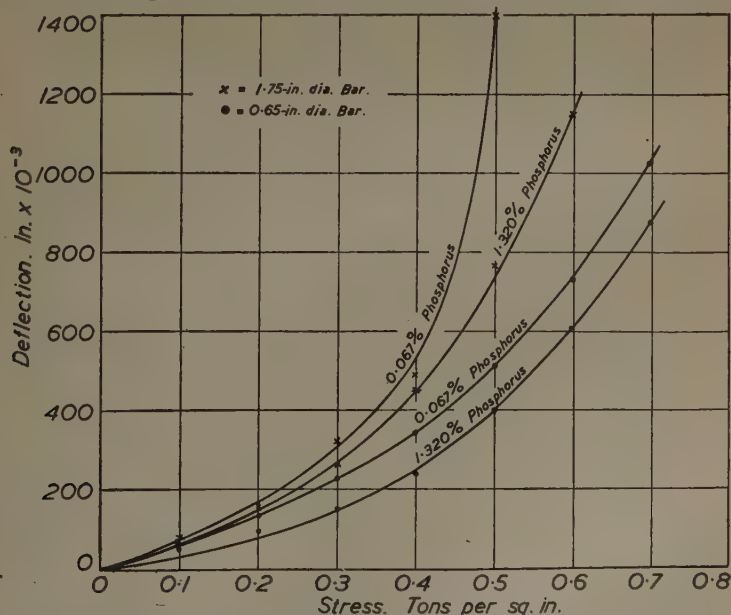
FIG. 6.—Deflection of Bars of Differing Phosphorus Contents, Series *D*, at 850° C. (The two lower curves also constitute Series *C*, high and low phosphorus contents.)

1941—ii   H

contents, but contain different amounts of phosphorus.   It will be seen that the smaller-cast bars resist deflection at 850° C. better than the larger bars of the same composition in each case.   The large-cast-diameter high-phosphorus bar is more rigid than the large-diameter low-phosphorus bar, showing that the phosphorus has a stiffening influence, even in large-diameter bars.   The finer graphite size of the 0·65-in. dia. bars (Figs. 21 and 23) compared with the larger-cast-diameter bars (Figs. 22 and 24) will be noted.

Fig. 7 shows the effect of the original casting section on the stiffness of bars 13A and 13B and 14A and 14B.   Both these bars
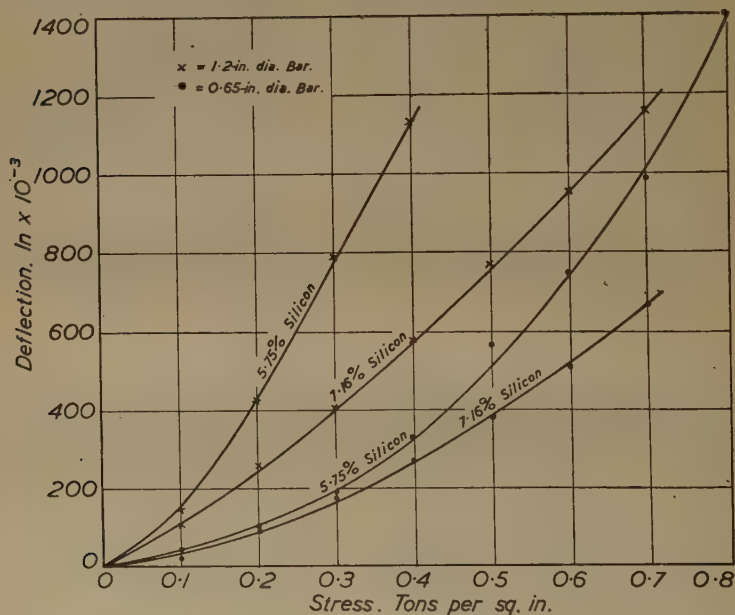
FIG. 7.—Deflection of Bars of Differing Silicon Contents, Series D, at 850° C.

have high silicon contents and good heat-resisting properties.   Here again the smaller bar in each case is better able to resist deflection than the larger bar of the same composition.   While the higher-silicon bars are stiffer than the lower-silicon-content bars of the same as-cast size, the lower-silicon 0·65-in. dia. as-cast bar is stiffer than the higher-silicon 1·2-in. dia. bar.   The relatively coarse graphite structures of the large-cast-diameter bars will be noted in Figs. 26 and 28.

These tests show that, for the same composition, a cast iron with coarse graphite has less resistance to deflection at high temperatures than an iron containing fine graphite.   Both silicon and

phosphorus increase the stiffness of coarse-graphite cast irons at the temperature of the tests.

An examination of the structures of the bars in the preceding series, however, in relation to their rigidity and composition, shows that small differences in graphite size are unimportant and have less influence on resistance to deformation at the temperature of the test than relatively small changes in composition. It will be seen, for example, that bar 4, the structure of which is shown in Fig. 14, was more rigid than bar 3, with the structure depicted in Fig. 13. Here an increase of approximately 0·5% of silicon has more than offset the influence of the coarser graphite structure in bar 4.

In Series B, bar 10, with the structure shown in Fig. 20, was more rigid than bar 9, *see* Fig. 19. A difference of 0·173% of phosphorus has counteracted the effect of the coarser graphite structure of bar 10.

An examination of the results obtained from the bars of Series D, however, shows that large differences in graphite size have a greater influence on rigidity than comparatively large differences in composition. It will be seen that bar $11A$, having the structure shown in Fig. 21, was more rigid than bar $12B$, which had the coarse graphite structure illustrated in Fig. 24, but which contained 1·2% more phosphorus. Bar $13A$, with the structure shown in Fig. 25, resisted deflection more successfully than bar $14B$, with the structure reproduced in Fig. 28, although the latter contained approximately 1·4% more silicon.

The Rigidity of Carbon Steels at 850° C.

Three plain carbon steels, forming Series E, were tested in order to obtain a comparison between their resistance to deflection at 850° C. and that of cast iron. They had typical low, medium and high carbon contents, the analyses being given in Table IV.

The test bars were machined from normalised steel rod, 0·75 in. in dia.

TABLE IV.—*Compositions of Steel Bars, Series* E (*Increasing Carbon Contents*).

No.	C. %.	Si. %.	Mn. %.	S. %.	P. %.
15	0·02	0·002	0·40	0·062	0·061
16	0·46	0·062	0·64	0·034	0·008
17	0·84	0·164	0·31	0·035	0·025

The deflections of these bars are shown in Fig. 8. It will be noted that the 0·02% carbon steel gave a deflection curve some-

what different from those obtained on the cast irons. Deflection is
at first fairly rapid and then slows up, finally becoming rapid again.
A possible explanation for this was found when a section from the
parallel part of the bar after test was examined under the microscope.
This showed that crystal growth had taken place to a very con-
siderable extent. It appears probable that as the crystals became
larger, the resistance of the bar to deflection at high temperatures
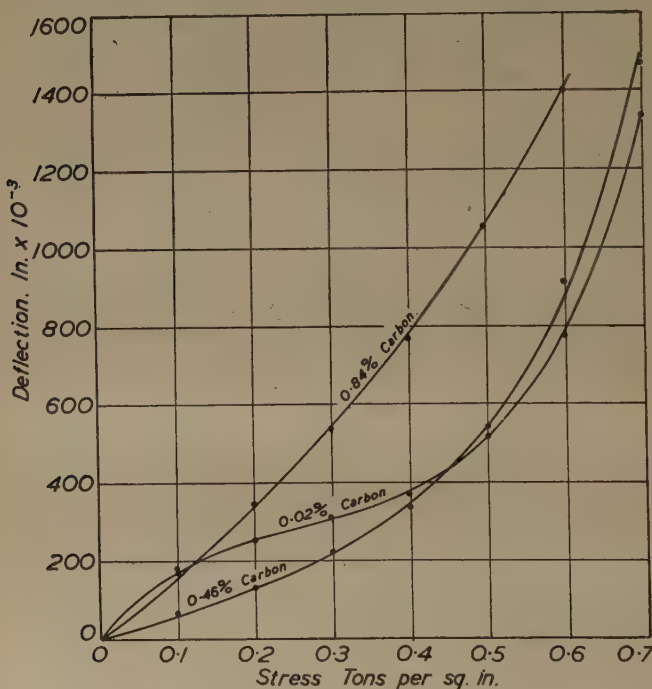
FIG. 8.—Deflection of Steel Bars, Series E, at 850° C.

was increased. This conclusion is supported by the results obtained
on the 0·84% carbon steel ; little grain growth occurred and
the deflection curve of this bar is smooth. The bar scaled rapidly
and the rapid deflection at the end of the test was no doubt due to
wastage of the specimen. Figs. 29 to 34 show the structures of the
three bars before and after the test, the latter being taken from the
stressed portion of the specimens. Grain growth has taken place
to a considerable extent in the 0·02% carbon steel bar and to a
smaller extent in the 0·46% carbon steel bar. There is little
change in the structure of the 0·84% carbon steel after the test.

When these results are compared with those for the cast irons, it is found that the high-carbon (0·8%) steel deflected considerably more than any of the cast irons tested, with the exception of those with very coarse graphite structures (large-diameter bars). The medium-carbon (0·4%) steel has a resistance to deflection comparable with that of a cast iron containing 5·75% of silicon (0·65-in. dia. bar).

The Rigidity of Austenitic Heat-Resisting Cast Irons at 850° C.

The most important of the recently developed heat-resisting cast irons are the highly alloyed austenitic irons known as Ni-Resist and Nicrosilal. The former contains nickel, copper and chromium, and the latter nickel, silicon and chromium. Both types of iron are made in a range of compositions to suit various conditions of service. Increasing the chromium content usually results in an increased resistance to scaling and growth, but high chromium renders the metal hard and practically unmachinable in the as-cast state. Two irons of each type, with high and low chromium contents, were tested, the compositions for this Series (F) being as given in Table V.

TABLE V.—*Compositions of Alloy Heat-Resisting Irons, Series* F.

No.	T.C. %.	Si. %.	Mn. %.	S. %.	P. %.	Ni. %.	Cr. %.	Cu. %
18	2·51	1·63	0·53	0·073	0·270	16·40	2·51	7·35
19	1·79	5·90	0·76	0·027	0·033	17·15	1·95	...
20	2·23	2·00	0·54	0·029	0·190	15·74	11·95	7·10
21	2·18	4·91	0·49	0·039	0·031	18·65	7·25	...

All the bars were cast in green-sand moulds from metal melted in a coke-fired crucible furnace. The metal was produced from charges consisting of Swedish white iron (3·8% total carbon), ferro-silicon (40% silicon), Armco iron and ferro-chromium (70% chromium, 1·5% carbon), with small additions of ferro-phosphorus and ferro-manganese. Nickel was added as nickel F shot, and copper scrap was used for additions of this element. In each case the metal was melted down and superheated for 15 min. before pouring. The as-cast size of the bars was 0·75 in. in dia.

The resistance of these irons to deflection under load at high temperatures is shown in Fig. 9. The higher-chromium bars of each type are more rigid than those lower in chromium. The higher-silicon material offers a greater resistance to deflection than the lower-silicon bars, in both the high- and low-chromium compositions. The as-cast structure of these bars is shown in Figs. 35 to 38. The rapid deflection of the high-chromium high-silicon iron in the early stages of the test may be due to a change in structure

taking place. It will be seen from the microstructure, Fig. 38, that in the as-cast state the structure is composed of cementite and austenite. Evidence is available that in irons of this composition carbide is deposited from the solid solution in the early stages of heating. It is possible that the resistance of the bar to deflection would be reduced while this structural change was taking place. It would appear that irons of this type should be well
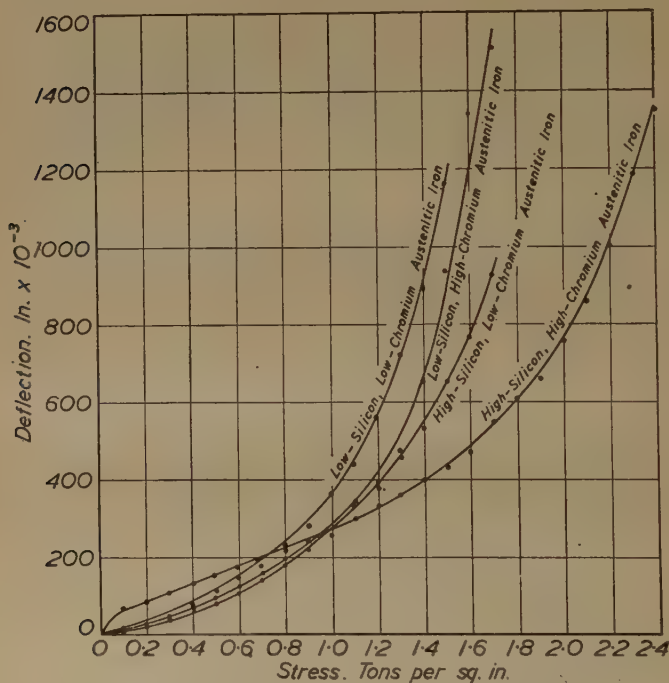
FIG. 9.—Deflection of Series *F* Bars at 850° C.

annealed at a temperature of 850–900° C. before being put into service. These tests show that austenitic high-silicon nickel irons are more rigid at high temperatures than austenitic copper-nickel irons, and that additions of chromium increase the stiffness of austenitic cast irons at 850° C.

Fig. 10 shows a comparison of the resistance to deflection at 850° C. of a steel, an ordinary good-quality grey cast iron, a high-phosphorus grey iron, a good heat-resisting iron of the Silal type, a high-silicon iron and a highly heat-resistant austenitic iron.
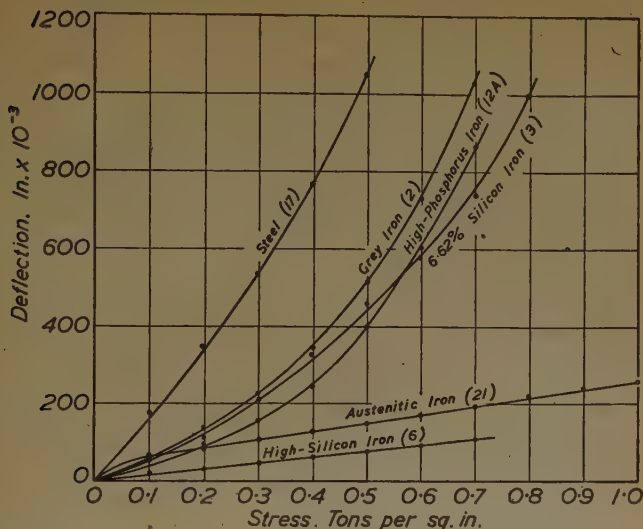
FIG. 10.—Deflection of Cast Irons and Steel at 850° C.

CONCLUSIONS.

Many factors influence the resistance to deflection of cast irons at elevated temperatures. Normal engineering irons have little resistance to growth and scaling and will, of course, fail from these causes under prolonged heating.

High-silicon cast irons of the Silal type were found to have a good measure of stiffness at 850° C. Higher-silicon irons (7–9% of silicon) have an excellent resistance to scaling and growth, and an increased resistance to deflection. These irons would be expected to have a much longer life than straight grey irons under most conditions of high-temperature service. The tests carried out show that such irons are capable of undergoing considerable deflection at 850° C. without fracture.

The high-silicon acid-resisting type of iron (14% of silicon) was found to be very rigid at 850° C. This type of iron is, however, extremely brittle in the cold, and although proved to be relatively ductile at a temperature of 850° C., would possibly crack if subjected to rapid changes in temperature.

At the temperature at which these tests were carried out, additions of phosphorus were found to be beneficial in increasing the resistance of cast iron to deflection; this was particularly so in the case of the higher-silicon irons. It should, however, be noted that the phosphide eutectic melts at a temperature of approximately 960° C., and at temperatures of this order the presence of

relatively small quantities of phosphorus is sufficient to cause almost complete loss of mechanical strength.

The austenitic irons Nicrosilal and Ni-Resist were found to have a good resistance to deflection at 850° C. As these irons also have a marked resistance to scaling and growth, they are suitable for use under many conditions of service.

Graphite size has an important influence on resistance to deflection at high temperatures. It would appear necessary that grey cast iron for high-temperature service should have as fine a graphite structure as possible. This may be obtained by relatively rapid cooling of the metal from the molten state, or by the use of a low total-carbon content. The thickness of the casting should be kept to a minimum, as thick sections cool slowly and this normally yields a coarse graphite structure. Slight differences in graphite size are, however, of less importance than relatively small changes in composition, e.g., in silicon or phosphorus content.

Three plain carbon steels were tested, and it was found that these had less resistance to deflection at 850° C. than many of the cast irons examined.

In using the data obtained from these tests in deciding on the most suitable type of iron for service at high temperatures, the conditions of service must be taken into account. If, for example, the service conditions entail heating the casting slowly to a uniform temperature, it is thought that an iron which is highly resistant to deflection will give better service than one which is less resistant. On the other hand, if the service conditions are such that the casting is subjected to steep temperature gradients, then it is possible that some stiffness must be sacrificed, and a less rigid iron will be better able to withstand these conditions. It is known, for example, that the high-silicon cast irons, shown to be very resistant to deflection at high temperatures, are susceptible to cracking under conditions where temperature gradients exist, while hematite irons with a coarse graphite structure give good service under conditions where considerable and rapid changes in temperature occur.

DOLOMITE BRICKS FOR USE IN STEEL-WORKS.[1]

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(Figs. 2 to 6 = Plates XV. and XVI.)

ABSTRACT.

Further replacement of magnesite and chrome-magnesite bricks by dolomite bricks in open-hearth and reheating furnaces would reduce the strain on shipping and leave home-produced magnesite available for positions in which its use is at present essential.

Calcined dolomite, which tends to " perish," owing to hydration (even if electrically fused), can be rendered stable by firing it in a rotary kiln with a suitable admixture of serpentine and other stabilisers. Bricks made from such clinker do not contain free lime and do not " dust " owing to dicalcium-silicate inversion. They compare favourably in properties with magnesite bricks, but have a somewhat lower resistance to thermal shock and to slags high in iron oxide.

They have been used with complete success in the tap-holes, hearths and banks of fixed open-hearth furnaces and in the banks and top layers of the sub-hearths of tilting furnaces. They have also given good service in reheating furnaces operating at temperatures at which scale formation is considerable.

Dolomite bricks in which the lime is protected from hydration by a coating of flux have a higher thermal shock and slag resistance and give lives equal to those of chrome-magnesite bricks in fixed open-hearth-furnace back walls.

Limited success has also been obtained in exposed positions with stabilised bricks in which the intermediate dolomite fraction was replaced by magnesia, while 80/20 magnesite-dolomite bricks have given encouraging results in preliminary trials in tilting-furnace back walls.

THE object of the present paper is to draw attention to certain experiences in the use of stable and semi-stable dolomite bricks and to suggest that in view of the increasingly difficult shipping position even more use should be made of such home-produced refractories.

In suggesting such replacement, the authors have borne in mind that the present-day furnace depends more than ever on the use of basic refractories in the back wall, front wall and ports for its high rate of steel production and do not therefore recommend any change that would be likely to result in a loss of output.

EARLY HISTORY.

The crux of the dolomite-brick problem lies in the fact that high-temperature calcination (or even electrical fusion) of dolomite does not yield a stable product. Both the magnesia and the lime formed according to the reaction :

$$CaCO_3.MgCO_3 \rightleftharpoons MgO + CaO + 2CO_2$$

are of moderate crystal size (about 0·05 mm. in dia.), but the lime, unlike the magnesia, hydrates readily and samples of " basic " made in this way start to " perish " after only a few days' exposure to the atmosphere. The term " dead-burned " dolomite, considered literally, is, therefore, a misnomer and resort must be had to other means if satisfactory stabilisation is to be obtained.

The ceramic literature of the last twenty years contains numerous suggestions as to how dolomite can be stabilised or the lime fraction removed altogether. Certain of the methods suggested are almost fantastic, while others, although showing promise, fall short of being a commercial proposition.

Perhaps the first really successful experiments on a works scale were made in Great Britain, when, in 1934, bricks consisting of a 75/25 mixture of dolomite and Sudanite rock [1] (magnesite + talc) were found to give encouraging results in open-hearth furnaces.

Although the modern brick is made with a serpentine addition instead of Sudanite rock, and big improvements have been made in the methods of clinker production, grading, pressing, drying and firing, the general type and composition of all the stable-dolomite bricks now in use in Great Britain are essentially similar to those of the bricks made in 1934.

Thus, bricks submitted to Messrs. Steel, Peech and Tozer in August, 1935, were shown to have the following properties :

Analysis.			Properties.		
SiO$_2$	.	. 13·24%	Porosity	. .	. 22·4%
FeO	.	. 3·21%	True specific gravity	.	3·32
Al$_2$O$_3$	.	. 1·23%	Refractoriness-under-load	.	25 lb. per sq. in.
MnO	.	. 0·05%	Fail temperature	.	. Over 1580° C.
CaO	.	. 39·64%			
MgO	.	. 41·74%			

Comparison of the above results with data given later in this paper for the present-day brick serves to show that even in 1934 the dolomite brick was well on the way to success.

These first bricks were made by firing clots of suitable composition, followed by regrinding, pressing in a small hydraulic press and firing in a baby kiln. They showed a serious brick-to-brick variation and periodically suffered from two serious limitations, viz., hydration in storage and " dusting " in the furnace.

[1] W. H. Tyler and W. J. Rees, *Transactions of the Ceramic Society*, 1934, vol. 33, p. 104.

Suggestions had already been made as to the cause of these difficulties, and complete confirmation came in February, 1936, when X-ray examination by Dr. A. H. Jay, of the Central Research Department (The United Steel Companies, Ltd.), in collaboration with Sir Lawrence Bragg, F.R.S., then of Manchester University,
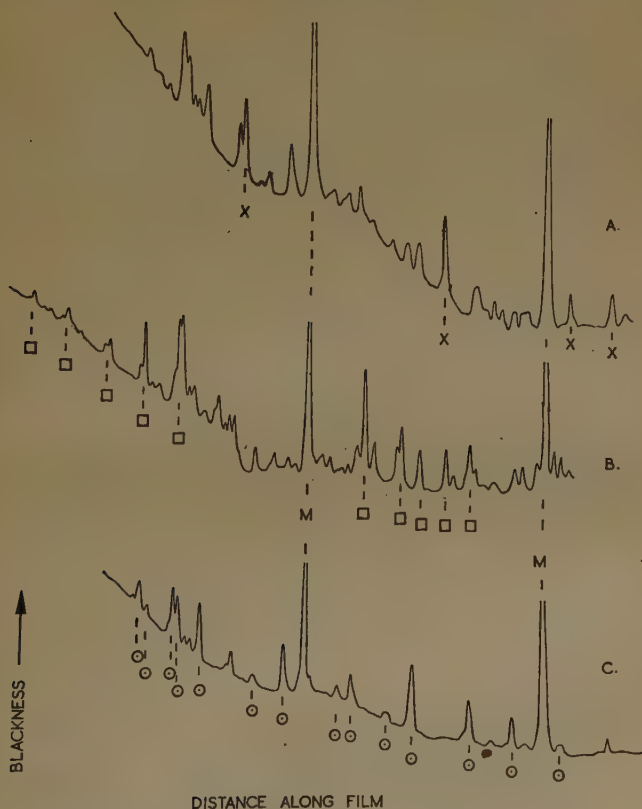
A.—Unstable dolomite brick containing CaO ($\times$).
B.—Dusted dolomite brick containing γ 2CaO.SiO$_2$ ($\square$).
C.—Stable dolomite brick consisting of 3CaO.SiO$_2$ ($\odot$) and magnesia (*M*).

Fig. 1.—Photometer Curves of Debye-Scherrer X-Ray Photographs.

showed that the bricks which hydrated contained small amounts of uncombined lime, owing to an insufficient silica content or inadequate firing, while those which " dusted " (like an electric-furnace white falling slag) after use in the open-hearth furnace contained γ dical-cium silicate (*see* Fig. 1). This work emphasised the necessity of

adjusting the chemical composition so that all the lime was combined but no unstable dicalcium silicate was present. It was therefore decided that the composition should be such that the principal constituents in the clinker were tricalcium silicate ($3CaO.SiO_2$) and magnesia, the reactions involved being essentially :

$$6(CaCO_3.MgCO_3) + 3MgO.2SiO_2.2H_2O \longrightarrow$$
$$\underset{\text{Dolomite.}}{} \qquad \underset{\text{Serpentine.}}{} \qquad 2(3CaO.SiO_2) + 9MgO + 2H_2O + 12CO_2.$$
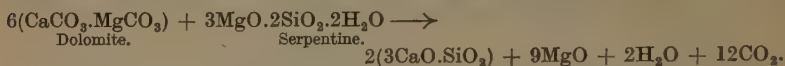
Since a slight decrease in the serpentine addition below that theoretically required results in the presence of free lime, it is considered wise to keep slightly on the silica-rich side of the $3CaO.SiO_2$ composition. This may result in the presence in the clinker and fired brick of a little dicalcium silicate, and, hence, certain of the known stabilisers are added to the batch to prevent its inversion from the β to the γ form, a change that occurs below 675° C. with a disastrous increase in volume. X-ray examination of numerous samples made during the last few years confirms that the main products are, in fact, magnesia and tricalcium silicate, but that small amounts of β dicalcium silicate may also be present. The state of combination of the alumina and iron oxide has not been ascertained at all definitely, although it would seem likely that they occur either as glass or as brownmillerite ($4CaO.Fe_2O_3.Al_2O_3$).

One other reaction requires to be considered before the general principles involved can be understood, viz., the tendency of tricalcium silicate to break down at moderate temperatures—in particular, round about 1200° C.—to give dicalcium silicate and free lime : [1]

$$3CaO.SiO_2 \rightleftharpoons 2CaO.SiO_2 + CaO.$$

The reaction is generally sluggish, but, as will be shown later, it can be troublesome in connection with the firing and subsequent storage of dolomite bricks.

The Production of Stabilised-Dolomite Clinker.

The batch used consists of high-grade raw dolomite, together with serpentine and small amounts of stabilisers. The materials are first wet-ground in a tube mill and then pass to a slurry tank where they are kept stirred until being fed into the top of a rotary kiln (see Fig. 2).

The firing zone of the kiln is lined with magnesite bricks, although special dolomite bricks have recently been used with marked success. The kiln is fired with pulverised coal and attains a temperature in excess of 1600° C. As the slurry passes through the kiln it first loses water, then carbon dioxide from the dolomite. From then onwards, reactions occur which eventually lead to the

[1] E. Carlson, *Journal of Research of the National Bureau of Standards,* 1931, vol. 7, No. 5, p. 896.

formation of $3CaO.SiO_2$ and MgO. If the temperature in the firing zone is particularly high, the pea-size particles tend to grow and may even yield balls of clinker several inches in diameter. The red-hot clinker leaving the bottom of the kiln passes through a cooler and thence *via* elevators to the crushers. The crushed product is mechanically sieved and the sieve fractions are stored in steel hoppers.

MANUFACTURE OF STABILISED-DOLOMITE BRICKS.

The various grades of clinker obtained in this way are recombined by weighing out fixed quantities of the different grain-size fractions and conveying them to a mixer. The grading of the batch varies somewhat from plant to plant, but the following may be considered a typical range :

Coarse	.	.	.	.	75 to 55%
Medium	.	.	.	.	15 ,, 5%
Fines	.	.	.	.	40 ,, 20%

The batch is moistened with about 4% of water, and weighed quantities are placed in the brick boxes of a hydraulic press (*see* Fig. 3). The moulding pressure used is generally between 10,000 and 15,000 lb. per sq. in.

The drying of dolomite bricks has given rise to a number of difficulties, in spite of their low moisture content. The cause of these troubles is still rather obscure, but it is known that they can be minimised if the drying is done at as low a temperature as possible and in a stream of dry clean air. If the drying conditions are not right, considerable cracking of the bricks may occur either in the drier or during subsequent kiln-firing.

The firing is carried out in down-draught kilns, either circular or rectangular, using coal, oil or producer gas as a fuel (*see* Figs. 4 and 5). The maximum temperature is 1400–1450° C. If insufficient firing treatment is given, *e.g.*, if a firing temperature of only 1300° C. is employed, some of the tricalcium silicate may break down in the manner already indicated and the product will then contain free lime. This may result in crumbling in storage. There is little doubt that some of the $3CaO.SiO_2$ in the clinker breaks down however dolomite bricks are fired, but considerable evidence obtained in both laboratory and works tests shows that any lime that may be formed in this way recombines during subsequent firing of the bricks at higher temperatures. A convenient indication of the firing treatment is afforded by the firing shrinkage, which is approximately $\frac{3}{16}$ in. on the 9-in. length of a standard square.

MANUFACTURE OF SPECIAL DOLOMITE BRICKS.

(1) *Semi-Stable Bricks.*

Some of the earliest bricks to give useful service in steelworks (particularly in arc-furnace side walls) were of the semi-stable type.

They contained large quantities of free lime, but could be stored long enough to make their use practicable and had a fairly good thermal-shock and slag resistance.   Bricks of this type can be made by mixing " basic " with a flux or slag, moulding with a temporary bond, e.g., tar, and firing in the ordinary way.   They are difficult to make and often difficult to store, but, as will be shown later, have a useful, if limited, application.

(2) *Dolomite-Magnesite Bricks.*

It has been shown that the replacement of the intermediate fraction in a stabilised-dolomite brick by dead-burned magnesite results in an increase in thermal-shock resistance.   Thus a spalling resistance index of 30 reversals [1] can sometimes be obtained in this way, as compared with one or two reversals for the normal stabilised brick.   The manufacturing technique, apart from the change in batch composition, is similar to that of the ordinary brick.

(3) *Dolomite-Chrome Bricks.*

A great deal of work has been done on dolomite bricks made with additions of chrome ore.   The change is purely one of batch composition, the object being to increase the thermal-shock resistance.

(4) *Magnesite-Dolomite Bricks.*

At the other extreme, magnesite bricks have been made in which 20% or 40% of the magnesite was replaced by stabilised-dolomite clinker.   Here, again, the manufacturing conditions are similar to those of magnesite brick-making, apart from the change in batch composition.

PROPERTIES OF DOLOMITE BRICKS.

(a) *Stabilised-Dolomite Bricks.*

The general properties of two typical dolomite bricks and of the magnesite bricks which they replace are shown in Table I.   A selected analysis of one such brick is as follows :

Silica	.	. 14·44%	Lime	.	. 40·04%
Ferric oxide	.	. 3·44%	Magnesia .	.	. 40·30%
Alumina .	.	. 1·50%	Loss on ignition		. 0·25%

It will be seen that the porosity and permeability of such dolomite bricks are of the same order as those of the magnesite bricks, whilst they show equally good volume stability at 1500° C. Their cold crushing strength is high, as is also their refractoriness-under-load, whether determined by the rising-temperature or by the maintained-temperature test.   The thermal-shock resistance is rarely greater than two reversals, whereas 5–8 reversals are more

[1] The test methods used are those described by one of the authors (J. H. C.) in a recent article in *Iron Age*, 1941, vol. 147, Feb. 6, p. 33; Feb. 13, p. 47.

usual with magnesite bricks, while special bricks such as the *M*4 in Table I. withstand 30 reversals without cracking.

TABLE I.—*Properties of Basic Open-Hearth Furnace Bottom Bricks.*

	Special Magnesite Brick.	Ordinary Magnesite Brick.	Typical Stabilised-Dolomite Bricks.	
Code No. :	*M*4.	*M*17.	*X*6.	*X*7.
Apparent porosity . . .	24·2	18·7	22·1	24·7
Bulk density :				
G. per ml. . . .	2·67	2·89	2·58	2·53
Lb. per cu. ft. . . .	167	181	161	158
Apparent specific gravity .	3·52	3·56	3·31	3·36
Cold crushing strength (9 × 4½ × 3-in. brick, on end).				
Lb. per sq. in. . . .	7170	>8300	>8300	5090
Permeability to air (perpendicular 9 × 3-in. face, through 1 skin). C.g.s. units . .	0·08	0·12	0·088	0·12
After-contraction (2 hr., 1500° C.). %	1·0	0·1	0·0	0·2
Refractoriness-under-load (maintained-temp. test : 25 lb. per sq. in. at 1600° C.)	Failed in 11 min.	Not determined.	Failed in 32 min.	Failed in 11 min.
Rising-temp. test (50 lb. per sq. in.). ° C. :				
Initial softening . .	...	1450	1540	1460
Rapid softening . .	...	1520	1610	1510
Fail	...	1540	1680	1600
Thermal-shock resistance (No. of reversals required to produce failure) . . .	>30	7	2	3

In addition to the properties given in Table I. the following may be considered typical for the present-day stabilised-dolomite brick :

Thermal expansion (20–1000° C.) .	1·31%.
Thermal conductivity (1000° C. mean)	15 B.Th.U. (*cf.* magnesite, 25 B.Th.U.).
Specific heat (750–20° C.) . .	0·25₅.
Hydration resistance . . .	No crumbling after boiling in water for 24 hr.
Free lime	No free lime by the glycerol or White's test.

(b) *Other Types of Dolomite Bricks.*

(1) *Semi-Stable Bricks.*

A selected analysis of one such brick is as follows :

Silica . . :	4·27%	Lime . . .	51·66%
Ferric oxide . .	2·53%	Magnesia . .	38·21%
Alumina . . .	2·16%	Loss on ignition .	1·07%

It will be seen that the material does not differ greatly in analysis from the ordinary "basic" used for fettling open-hearth furnaces. The properties of samples of this type are summarised in Table II., column 1. It will be seen that, in addition to a comparatively low porosity and moderately good crushing strength, the brick has a fairly high refractoriness-under-load and an unusually good thermal-shock resistance. Furthermore, its resistance to slags high in iron oxide and lime is greater than that of the ordinary stabilised-dolomite brick. It has, however, one serious limitation, *viz.*, it can be stored for only a limited period.

TABLE II.—*Properties of Various Other Bricks Containing Dolomite.*

	1. Semi-Stable Dolomite Brick.	2. 80/20 Dolomite-Magnesite Brick (Special Grading).	3. 80/20 Magnesite-Dolomite Brick.	4. 60/40 Magnesite Dolomite Brick.
Porosity. %	22·8	26·4	19·2	20·4
Bulk density. G. per c.c.	2·52	2·50	2·79	2·72
Specific gravity (by porosity)	3·27	3·40	3·45	3·41
Crushing strength (9 × 4½ × 3-in. brick, on end). Lb. per sq. in.	3680	4700	8740	7380
Permeability (perpendicular to 9 × 3-in. face, through 1 skin). C.g.s. units	0·29	0·36	0·121	0·097
After-contraction (2 hr., 1500° C.). %	1·2	0·7	0·2	0·7
Refractoriness-under-load (50 lb. per sq. in.). ° C.:				
Initial softening	1360	1430	1370	1400
Rapid softening	1520	1500	1510	1580
Fail	1610	1700	1650	1710
Refractoriness-under-load (25 lb. per sq. in., maintained at 1600° C.).	...	10% deformation after 49 min.	...	...
Thermal shock resistance (No. of reversals required to produce failure).	23	5	15 >26	13 } 15 16
Slag resistance (when tested with "4Fe₂O₃.CaO," slag at 1650° C.).	Definitely higher than stabilised-dolomite brick. No "bursting" expansion with iron oxide.	Similar to that of stabilised-dolomite brick. No "bursting" expansion.	Only slightly inferior to magnesite. Show volume stability at this temperature.	

(2) *Dolomite-Magnesite Bricks.*

A typical analysis of a specially graded brick in which the stabilised clinker was replaced in the intermediate section by magnesia is as follows :

Silica	.	. 11·96%	Lime	.	.	. 31·40%
Ferric oxide	.	. 3·24%	Magnesia	.	.	. 51·60%
Alumina	.	. 1·60%	Loss on ignition		.	. 0·14%

PLATE XV.

FIG. 2.—Rotary Kiln Used for the Production of Stabilised Dolomite Clinker.

FIG. 3.—Hydraulic Pressing of Dolomite Brick.

[Swinden and Chesters.

[To face p. 112 P.

PLATE XVI.

FIG. 4.—Dolomite Brick Kiln Fired with Producer Gas.

FIG. 5.—The Setting in a Dolomite Brick Kiln.
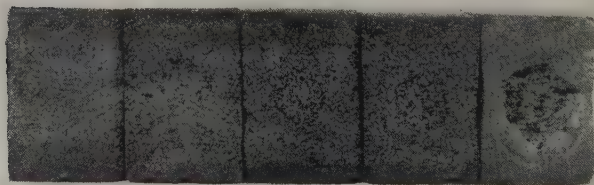
FIG. 6.—Effect of a 4/1 Ferric-Oxide/Lime Pill on (left to right) a 100/0, 80/20 60/40, 40/60 and 0/100 Magnesite-Dolomite Brick after 1 hr. at 1650° C.

[*Swinden and Chesters.*
[*To face p.* 113 P.

The properties of this brick are summarised in Table II., column 2. The brick is similar in many respects to the stabilised-dolomite brick, but has a thermal-shock resistance of 5 reversals. Batches have been made of which the thermal-shock resistance was much higher, *e.g.*, 15–30 reversals, but the problem of maintaining such values, both in brick-making and in use, is considerable. The specific heat of a brick of this type was found to be $0·25_5$, while its thermal expansion (20–1000° C.) was $1·26\%$.

(3) *Dolomite-Chrome Bricks.*

No description of these bricks will be given, although a considerable amount of laboratory test data are available. They possess one serious limitation, *viz.*, the tendency of the chrome to react at the working temperature with the dolomite clinker, with the production of a great deal of "melt." This results in serious softening, which has so far prevented their commercial application in steel furnaces.

(4) *Magnesite-Dolomite Bricks.*

Trial batches of magnesite bricks have been made in which 20% or 40% of the magnesite was replaced by stabilised-dolomite clinker. The properties of such bricks are summarised in Table II., columns 3 and 4. It will be seen that the samples examined had a low porosity, a high refractoriness-under-load and an unusually high thermal-shock resistance. Slag tests using a 4/1 mixture of iron oxide and lime (representing basic open-hearth furnace dust) showed that these bricks had a slag resistance only slightly inferior to that of magnesite itself. The change in slag resistance on passing from magnesite to dolomite brick is illustrated in Fig. 6, which shows the results of tests on laboratory-made samples.

APPLICATION TO STEELWORKS FURNACES.

The Open-Hearth Furnace.

The following extracts from Minutes of the Research Directing Committee of The United Steel Companies, Ltd., will serve to show that the dolomite brick, so extensively used to-day, only gained a foothold after competing with magnesite bricks *under pre-war conditions* :

Date of Minute.

Dolomite Bricks with Addition of Sudanese Rock.

16/1/35.

    (*a*) A trial panel, 5 courses high (from the fore-plate level), 23 in. long and 18 in. wide, built in the back wall of Stocksbridge (S. Fox & Co., Ltd.) *H* basic furnace slightly to the left of a position immediately

over the tap-hole, after 14 weeks' service was found to have the following thickness remaining :

					Dolomite Bricks with Sudanese Rock Addition.	Adjacent Magnesite Bricks.
Course	1	.	.	.	15 in. left.	16 in. left.
,,	2	.	.	.	14 ,,	14 ,,
,,	3	.	.	.	11 ,,	12 ,,
,,	4	.	.	.	10 ,,	9 ,,
,,	5	.	.	.	9 ,,	9 ,,

The above results would appear to warrant extended trials.

(b) 196 dolomite bricks, tested in the back wall of K furnace at Templeborough were found to have 1 in. less good surface than magnesite bricks in a similar position.

(c) The tap-hole of G furnace at Templeborough has just been lined on each side with a 3-ft. 6-in. patch of these bricks.

16/9/35.

The trial patch in the lining of the tap-hole in G furnace at Templeborough still continues to function satisfactorily.

14/11/35.

Upon cutting out the tap-hole of G furnace at Templeborough when down for repairs, the dolomite bricks were found to be in perfect condition and were put back again for a further run of about 26 weeks.

In this position, dolomite bricks are considered to be as good in every respect as magnesite bricks, which are much dearer.

1/4/36.

The trial of standard dolomite bricks in the tap-hole of G furnace at Templeborough has now been completed, the bricks having been in service for 42 working weeks, during which 519 casts have been produced, with an output of 41,765 tons.

The bricks were still in perfect condition, but some were damaged in taking them out. In this position, Steel, Peech and Tozer consider these bricks to be fully equal to magnesite bricks.

8/11/37.

Templeborough tap-hole trials.

After 28 weeks in D furnace, the dolomite bricks were generally as good as a magnesite-brick tap-hole.

Equally satisfactory results were obtained in a later trial in G furnace, despite the fact that, in the latter case, examination of the tap-hole revealed steel to be present between each layer of dolomite bricks.

As a result of the above trials and similar tests made at Appleby-Frodingham, dolomite bricks have been widely applied in the open-hearth furnaces of The United Steel Companies, with a considerable saving in money in peace-time, and with an even more important saving in shipping at the present time.

The positions in which they have been found to give satisfactory service are summarised in Table III. and in Fig 7.

TABLE III.—*Dolomite Bricks in Open-Hearth Furnace.*
Present Standard Practice.

Position.*	Type of Brick.	Comments.
7 Bath bottom.	Stabilised-dolomite.	Replaces all magnesite bricks in fixed furnaces and top course in tilting furnaces.
8 Bridge bank. } 9 Banks. }	Stabilised-dolomite.	Complete replacement in fixed furnaces and partial replacement in tilting furnaces.
12 Back walls.	Semi-stable.	Life in fixed furnaces similar to chrome-magnesite bricks.
	Dolomite-magnesite.	Limited success in fixed furnaces.
	Magnesite-dolomite (80/20).	Trials in tilting furnaces gave life approx. equal to chrome-magnesite bricks.
	Magnesite-dolomite (60/40).	Trials in tilting furnaces suggest inferior to chrome-magnesite bricks.

* *Cf.* First Report on Refractory Materials, p. 212, *Iron and Steel Institute*, 1939, *Special Report No.* 26.
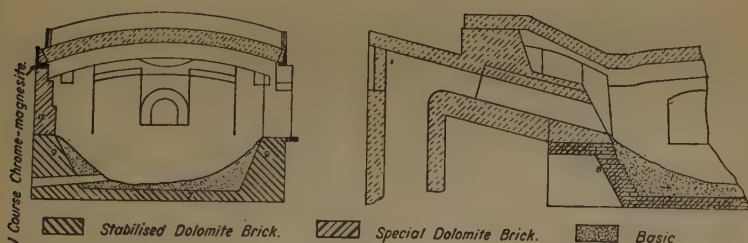
FIG. 7.—Main Positions in Basic Open-Hearth Furnaces in which Dolomite Brick and Basic are Employed.

Bath Bottom, Banks and Bridge Banks.

The encouraging results obtained with stabilised-dolomite bricks in tap-holes has led to a gradual replacement of magnesite bricks in fixed-furnace hearths by dolomite bricks, until to-day the authors' company has no hesitation in building a new hearth without any magnesite bricks at all. With tilting furnaces working the hot-metal process the hearth is rarely seen, and hence it is not surprising that replacement has proceeded more gradually. It has, however, been found that stabilised-dolomite bricks can be used with fair success in the back banks where they can be seen and fettled, and, as a result, partial replacement of the hearth bricks has been tried. Thus, at one plant eight courses in the back wall around the furnace ends, four above and four below the sill, are used, the bricks extend-

ing for the full thickness of the lining. About 3000–4000 dolomite bricks are used for a normal repair in positions in which magnesite bricks were previously employed. In the front banks of tilting furnaces the use of dolomite bricks is more doubtful, since fettling is difficult.

The use of bricks in the sub-hearth is essentially an insurance against premature failure of the monolithic hearth, and hence, unless such failure actually occurs, the bricks are not subject to any real test. It will therefore be asked whether, in fact, break-outs have been more frequent when using dolomite bricks. Even if all other variables were controlled, a fair answer to this question could be given only after a long period of years. All that can be said at the moment is that, in the authors' experience, the break-outs on furnaces having dolomite-brick hearths have actually been less in proportion to the number of hearths lined in this way than have been experienced with magnesite during the same period. In one case, where a break-out did occur through a sub-hearth consisting of dolomite bricks, the latter were critically examined in the laboratory. Chemical analysis showed that the iron-oxide content had increased in the top layers from 3% to 17%, and there had been a corresponding drop in the magnesia content. The silica was only 8·6%, i.e., less than in the original brick, presumably owing to the diluting action of slags high in iron oxide and lime. This result, which falls in line with later studies on open-hearth furnace bottoms, suggests that dolomite bricks used in this position tend to become similar in composition and texture to the adjacent " basic." There is, therefore, no reason to believe that, if a hearth wears thin enough to expose the dolomite bricks, there will be any increase in the rate of wear. Indeed, at one steelworks, where the conditions had been particularly bad, it was stated that the dolomite bricks had stood up better than would have been expected of magnesite bricks.

Tests were also made on the " break-out " hearth to see whether prolonged heating at about 1200° C. had resulted in any dissociation of the tricalcium silicate. The bricks showed no crumbling on boiling in water for 24 hr., and there is no reason to believe that they were any less stable after use than magnesite bricks. Indeed, the percentage recoveries from used magnesite and dolomite hearths would appear to be of the same order.

Back Walls.

Attempts to use ordinary stabilised-dolomite bricks above the hearth level have mostly resulted in premature failure, owing to spalling. More recently, bricks have been produced—e.g., the dolomite-magnesite and semi-stable dolomite bricks mentioned earlier in this paper—that have given more encouraging results.

Thus, with the 80/20 type dolomite-magnesite brick, in which the magnesite is present in the intermediate section, back-wall trials in

fixed furnaces showed a life of about 8 weeks, as compared with 11 weeks for chrome-magnesite bricks.

Still more encouraging results have been obtained with semi-stable bricks, which have recently given back-wall lives of the same order as chrome-magnesite bricks. These bricks still possess one serious limitation—they must be used within a short time—although attempts are now being made to overcome this by impregnating the fired brick with organic stabilisers.

With tilting furnaces the position is more difficult, because the slag runs up the back wall during tilting. Some success has been obtained with small trials of stabilised-dolomite bricks, and more recently results approximately equal to those given by chrome-magnesite bricks have been obtained in trials of the 80/20 magnesite-dolomite type. Trials of semi-stable bricks are in hand, but it is too early to state whether these will be successful. Good results have also been obtained with stabilised-dolomite bricks in the splays of tilting furnaces.

Considerable quantities of imported chrome and magnesite are also used for the parging of tilting furnaces. Preliminary trials, using finely ground stabilised clinker, suggest that a cement of this type may, with some development, provide an adequate substitute.

Reheating Furnaces.

Scale formation may be so serious in reheating furnaces working at 1200° C. and upwards that the use of firebrick hearths is precluded. In such hearths, the use of chrome-magnesite or magnesite bricks has been usual, but in the last few years, extensive use has been made of stabilised-dolomite bricks with complete success.

Cement.

Special cements have been developed for use with stabilised-dolomite bricks. They consist essentially of finely ground stabilised-dolomite clinker, and can be used either wet or dry. No special precautions, such as the use of oil-bonded cements, are necessary with stabilised-dolomite bricks. With bricks of the semi-stable type, however, dry-setting or a non-aqueous cement must be employed.

SUMMARY.

(1) The further replacement of magnesite and chrome-magnesite bricks in open-hearth and reheating furnaces by dolomite bricks would reduce the strain on shipping and leave home-produced magnesite available for positions in which its use is at present essential.

(2) Dolomite, even after high-temperature calcination or electrical fusion, " perishes " fairly rapidly, owing to hydration of the

free lime.   It can be rendered stable by firing it in a rotary kiln with a suitable admixture of serpentine and dicalcium-silicate stabilisers.

(3) Bricks made from such clinker consist essentially of magnesia and tricalcium silicate ($3CaO.SiO_2$).   They should not contain free lime, but may contain some stabilised β dicalcium silicate.

(4) Given adequate control of the clinker and brick production, such dolomite bricks compare favourably in properties with magnesite bricks, although they have a somewhat lower resistance to spalling and to slags high in iron oxide.

(5) They have been used for many years with complete success in the tap-holes, hearths and banks of fixed open-hearth furnaces, and in the banks and top layers of the sub-hearth of tilting furnaces. They have also given good service in reheating furnaces operating at temperatures at which scale formation is considerable.

(6) Semi-stable dolomite bricks, *i.e.*, dolomite bricks in which the lime is protected from hydration by a coating of flux, have a higher thermal-shock and slag resistance, and have given a life equal to that obtained with chrome-magnesite bricks in fixed-furnace back walls.

(7) Limited success has also been obtained in exposed positions with stabilised-dolomite bricks in which the intermediate fraction was replaced by magnesia.

(8) Magnesite-stabilised dolomite (80/20) bricks have given encouraging results in preliminary trials in tilting-furnace back walls.

ACKNOWLEDGMENT.

A NOTE ON THE THEORY OF QUENCHING.[1]

By J. H. AWBERY, B.A., B.Sc. (Physics Department, The National Physical Laboratory, Teddington).

Synopsis.

The heat transfer to a fluid from the plane surface of a solid follows different laws according to the temperature of the surface. If this latter temperature is sufficiently far above the boiling point of the fluid, there is a regime in which a sheath of vapour forms between the solid and the fluid. It is shown that, during this regime, the heat loss H per unit area per second is $B(T_B - T_0)^{\frac{3}{4}}(k_l{}^2agc/\nu)^{\frac{1}{4}}$, where B is a constant, approximately $0 \cdot 0015$ if thermal quantities are measured in calories. The other symbols have the following meanings : T_B, boiling point of the fluid; T_0, temperature of the mass of the fluid; k_l, thermal conductivity of the fluid at the temperature $T' = (T_B + T_0)/2$; a, coefficient of cubic expansion of the fluid at temperature T'; g, acceleration due to gravity; c, specific heat of fluid per unit volume at temperature $T' = (T_B + T_0)/2$; ν, kinematic viscosity of fluid at temperature T'.

(1) *Introduction.*

A GOOD deal of experimental work has been carried out in recent years on the processes by which the heat is transferred from a heated object to a liquid in which it is immersed. Three regimes have been distinguished :

(1) If the body is sufficiently hot, there is first a period during which the body of the liquid is separated from the solid by a vapour film; the thermal conductivity of vapour is usually low, but the initially large temperature gradient results usually in the heat transfer being fairly considerable during this period.

(2) When the solid is cool enough and the film has become very thin, it breaks up so that over parts of the area the liquid and solid are in contact and at other parts bubbles form; by becoming detached, they carry off heat from the surface by a process of mass transfer. The heat transmission coefficient in this period is usually greater than during the film regime.

(3) When the solid is definitely below the boiling point of the fluid, so that neither film nor bubbles can form, the process is the normal one of pure convection, and the transmission coefficient is much smaller than in the first two regimes.

The third regime has been very thoroughly studied, at least as regards heat loss from cylinders, but the laws of the heat flow during the first and second are not yet fully established, and there is no information as to the exact factors governing the temperature of transition between them.   In the present note attention is confined to the first, or film, regime.

(2) *Approximate Theory of Heat Transfer in the Film Regime.*

Since our aim is to elucidate the processes occurring, it is preferable to take a highly simplified case, *viz.*, one in which the cooling solid is a thin uniform plate lying horizontally with the liquid above it, as shown in Fig. 1.   The film will be assumed to be of uniform
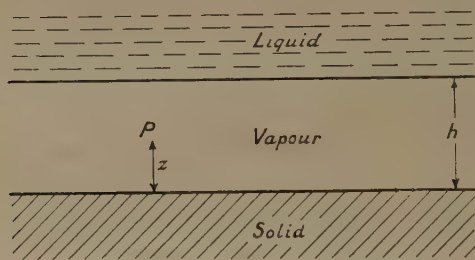
FIG. 1.—Diagrammatic Representation of the Vapour
Film between Liquid and Solid.

thickness h (which will, however, vary with time), as marked in the Figure.

In this simplified case, it is clear that the pressure throughout the vapour is uniform and equal to that required to support the weight of the liquid.   Whilst the regime lasts, therefore, the pressure will not vary with time, and, if the weight of the liquid is neglected, will be equal to the atmospheric pressure.   But this pressure must of necessity be the vapour pressure of the liquid at the temperature of its own surface, since otherwise more vapour would be formed, or all would condense.   Hence the temperature at the liquid-vapour boundary must be the boiling point (T_B) at the pressure prevailing, *i.e.*, to our approximation, at atmospheric pressure.   The solid will be assumed to be so thin that the temperature gradient within it may be neglected, so that its surface temperature, T_s, is also its mean temperature.[1]

The heat leaving unit area of the solid in time dt is Hdt, where H is the heat transfer per unit area per sec. for a surface at temperature T_s, and this heat will travel across the vapour by radiation and conduction (since we shall give reasons later for supposing that the film is too thin for convection to occur).   Assuming

[1] An alphabetical list of symbols is given at the end of the paper.

the vapour to be transparent to the radiation, the latter will not affect the temperature of the film, which will thus vary linearly with distance z from the solid-vapour boundary. In fact the temperature of the vapour is :

$$T_v = T_s - \frac{z}{h}(T_s - T_B) = T_s\left(1 - \frac{z}{h}\right) + \frac{zT_B}{h}.$$

Equating the heat lost by the solid to that travelling by radiation and conduction we have :

$$H = E\sigma(T_s^4 - T_B^4) + \frac{k_v(T_s - T_B)}{h} \quad . \quad . \quad . \quad (1)$$

where E is the thermal emissivity of the solid, σ is Stefan's constant, k_v is the thermal conductivity of the vapour, and temperatures are understood to be measured on the absolute scale. In the case contemplated, $H = -W dT_s/dt$, where W is the heat capacity per unit area of the plate, and equation (1) is equivalent to :

$$\frac{-W dT_s}{dt} = E\sigma(T_s^4 - T_B^4) + \frac{k_v(T_s - T_B)}{h} \quad . \quad . \quad . \quad (1a)$$

The heat reaching the liquid differs from that leaving the solid, since it includes also the latent heat of any vapour which condenses, $viz.$, $-L\dfrac{dm}{dt}$, where m is the mass of vapour per unit area of surface, so that the heat reaching the unit area of the liquid per second is :

$$E\sigma(T_s^4 - T_B^4) + k_v\frac{(T_s - T_B)}{h} - L\frac{dm}{dt} \quad . \quad . \quad . \quad (2)$$

We note, however, that, provided there is sufficient liquid, this quantity must remain constant throughout the duration of the film regime, since the heat thus received at the surface of the liquid is carried away, by convection and otherwise, from a surface at constant temperature (the boiling point) to a mass of liquid at constant temperature with unchanging boundary conditions. An accurate expression for this flow is not available, but the results given by Fishenden and Saunders [1] suggest that the expression $Hd/k_l\theta = A(\alpha g\theta d^3c/k_l\nu)^n$ gives a reasonable approximation for a cylindrical surface. Here H is the heat flow per unit area per unit time, d the diameter of the cylinder, k_l the thermal conductivity of the liquid, θ the temperature excess (in the present case $T_B - T_0$, where T_0 is the temperature of the fluid at a distance from the surface), c the specific heat of the liquid per unit volume, α its coefficient of expansion and ν its viscosity ; g is " gravity " and n a constant.

Thus :

$$H = Ak_l^{1-n}\theta^{1+n}\alpha^n g^n d^{3n-1}c^n\nu^{-n}$$

and since for sufficiently large cylinders the heat loss per unit area

[1] " The Calculation of Heat Transmission," p. 172. London, 1932 : H.M. Stationery Office.

tends to become independent of the diameter, we may assume that in the limit, when the diameter increases indefinitely and the cylinder becomes a plane, then $3n - 1 = 0$ or $n = \frac{1}{3}$, a result which may also be obtained by considering the dimensions directly.

We thus take for a plane surface the expression :

$$H = Ak_i^{\frac{2}{3}}\theta^{\frac{1}{3}}a^{\frac{1}{3}}g^{\frac{1}{3}}c^{\frac{1}{3}}\nu^{-\frac{1}{3}}, \text{ i.e., } A\theta^{\frac{1}{3}}(k_i^2agc/\nu)^{\frac{1}{3}}.$$

This is to be equated to expression (2), leading to the equation :

$$\sigma E(T_s^4 - T_B^4) + k_v\frac{(T_s - T_B)}{h} - L\frac{dm}{dt} = A(T_B - T_0)^{\frac{4}{3}}(k_i^2agc/\nu)^{\frac{1}{3}} \quad . \quad . \quad (3)$$

From equations (1) and (3) we eliminate h and m $\left(= \int_0^h \rho dz\right)$ by means of the gas law.   From the general equation for a perfect gas $(pV = RT)$ it follows that $p = \rho RT/M$, where ρ is the density and M the molecular weight.   Now, in the film, $T = T_s - z(T_s - T_B)/h$, and p is constant and approximately equal to 1 atm.   Thus :

$$\rho = \frac{Mph}{R[hT_s - z(T_s - T_B)]}$$

and

$$\int_0^h \rho dz = \frac{Mph}{R}\int_0^h \frac{dz}{hT_s - z(T_s - T_B)} = \frac{-Mph}{R(T_s - T_B)}\log\left[hT_s - z(T_s - T_B)\right]_0^h$$

$$= \frac{-Mph}{R(T_s - T_B)}\log\frac{T_B}{T_s} = \frac{Mph}{R(T_s - T_B)}\log\frac{T_s}{T_B}.$$

Thus :

$$m = \frac{Mph}{R(T_s - T_B)}\log\frac{T_s}{T_B} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

By comparison of equations (1a) and (3) we have :

$$-\frac{WdT_s}{dt} - L\frac{dm}{dt} = A(T_B - T_0)^{\frac{4}{3}}(k_i^2agc/\nu)^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad (3a)$$

which may be integrated with respect to t, giving :

$$WT_s + Lm + At(T_B - T_0)^{\frac{4}{3}}(k_i^2agc/\nu)^{\frac{1}{3}} = B \quad . \quad . \quad . \quad . \quad (5)$$

Substituting for m from equation (4) this becomes :

$$WT_s + \frac{LMph}{R(T_s - T_B)}\log\frac{T_s}{T_B} + At(T_B - T_0)^{\frac{4}{3}}(k_i^2agc/\nu)^{\frac{1}{3}} = B \quad . \quad . \quad (6)$$

and finally, eliminating h between equations (1a) and (6), we find :

$$WT_s - \frac{LMpk_v\log(T_s/T_B)}{R\left[\frac{WdT_s}{dt} + E\sigma(T_s^4 - T_B^4)\right]} + At(T_B - T_0)^{\frac{4}{3}}(k_i^2agc/\nu)^{\frac{1}{3}} = B. \quad (7)$$

This, on the assumption made, is the accurate differential equation giving the relation between T_s, the temperature of the solid which is being cooled, and the time t. The constants A and B are independent of the particular fluid. B might be expressed in terms of the initial (or final) conditions. Thus, if the curve of temperature against time is extrapolated to a time t_0 at which the film is of zero thickness, so that $m = 0$ and $T_s = T_B$, equation (5) shows that :

$$B = WT_B + At_0(T_B - T_0)^{\frac{1}{3}}(k_l{}^2 agc/\nu)^{\frac{1}{3}}$$

and equation (7) becomes :

$$W(T_s - T_B) - \frac{Lmpk_v \log (T_s/T_B)}{R[WdT_s/dt + E\sigma(T_s{}^4 - T_B{}^4)]} + A(t - t_0)(T_B - T_0)^{\frac{1}{3}}(k_l{}^2 agc/\nu)^{\frac{1}{3}} = 0 \quad . \quad .$$

In practice, of course, the film regime would have given place to the second regime before this condition was reached, but the extrapolation, serving to express the slope of the observed straight-line relation, appears to be legitimate.

(3) *Solution of the Equations to a First Approximation.*

It does not appear possible to integrate the differential equation (8) in finite terms. A good deal of information may, however, be obtained from an examination of the experimental results of Speith and Lange,[1] who studied the time-temperature curve when a silver ball was quenched from about 800° C. in water at different temperatures. Thus H in this case is $-WdT_s/dt$. In common with practically all workers, they found an almost exactly linear relation between time and temperature during the film regime, and from the curves it appears that dT_s/dt is 26·0, 15·6 and 12·0° C. per sec. for cooling by water at 20°, 40° and 60° C., respectively. Thus in equation (1) of the present paper, W, dT_s/dt (and hence H), σ, T_s at time t, T_B ($= 100°$ C.) and k_v are known. The last-mentioned quantity was estimated, at the high temperatures required, by means of Sutherland's equation with constants adjusted to fit the conductivities at the two temperatures for which values are given in International Critical Tables. There are thus two unknown quantities, E the thermal emissivity of silver, and h the thickness of the film. Numerical values were inserted in the equation and h was calculated, first assuming $E = 1$ (the highest possible value) and then $E = 0·05$ (the lowest likely value). The results are shown in Table I., and it should be noted that the calculation also shows that the two terms on the right of equation (1) are of comparable magnitude.

[1] *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung,* 1935, vol. 17, p. 167.

TABLE I.—*Computed Thickness of Vapour Film.*   (*Cm.*)

Condition.	Water Temperature. ° C.					
	20°.	40°.	60°.	20°.	40°.	60°.
	Assuming E = 1.			*Assuming* E = 0·05.		
Initial	0·0180	0·040	0·053	0·026	0·090	0·194
At end of linear regime	0·0042	0·0046	0·0049	0·0044	0·0047	0·0051

Values of the same order were obtained for the film thickness by a similar analysis of some unpublished figures by T. F. Russell, in which the quenching fluids were organic materials of high boiling point. Taken together they seem to show that, under the conditions of such experiments, the vapour film is so thin that convection cannot occur, and they thus substantiate the statement made earlier in this paper.

Equation (6) was next applied to Speith and Lange's data. For the six conditions dealt with before, *i.e.*, the beginning and end of the linear portion of the curves for water at 20°, 40° and 60° C., the values of WT_s vary from $1·35 \times 10^9$ to $2·74 \times 10^9$ dynamical units, whereas the second term $\dfrac{LMph}{R(T_s - T_B)} \log \dfrac{T_s}{T_B}$ varies from $0·000043 \times 10^9$ to $0·00145 \times 10^9$, even if the maximum possible value of h is taken.

It thus appears that the second term of equation (6) may be neglected in comparison with the others, and we thus obtain an immediate theoretical explanation of the widely observed fact that the time-temperature curves are approximately linear.

Moreover, the experimental results may now be used to deduce values of A and B.   All the quantities in the modified equation (6), including t, the time, are known (k_l, c and ν were taken from Kaye and Laby's Tables, at the appropriate temperatures) and hence the initial and final points of each curve give a pair of equations from which A and B may be calculated.   The results are shown in Table II., in the units which apply if thermal quantities are measured in calories.

TABLE II.—*Values of Constants* A *and* B.

	Water Temperature. ° C.			Mean.
	20°.	40°.	60°.	
A . . .	0·00178	0·00138	0·00140	0·0015
B . . .	65·4	65·7	65·8	65·6

The constancy of B leaves nothing to be desired. As regards A, which depends directly on the slope of the time-temperature curve, there are deviations of over 10%, but there does not appear to be a systematic trend in the values; since they are deduced from slopes which vary more than two-fold, the agreement is not unsatisfactory, particularly when it is remembered that the results apply to a ball 2 cm. in dia., and the theory to a flat plate.

The outcome of this section is to show that, at least for conditions similar to those in silver-ball tests with water, equation (6) reduces to:

$$WT_s + At(T_B - T_0)^{\frac{1}{3}}(k_i{}^2 agc/\nu)^{\frac{1}{3}} = B,$$

or expressing B in terms of the final state and inserting the numerical value of A,

$$T_s = T_B - 0.0015(T_B - T_0)^{\frac{1}{3}}(k_i{}^2 agc/\nu)^{\frac{1}{3}}(t - t_0)/W \quad . \quad . \quad (9)$$

Alternatively we may express B in terms of the initial conditions. If $T_s = T_s{}'$, when $t = 0$, the equation becomes:

$$T_s = T_s{}' - 0.0015(T_B - T_0)^{\frac{1}{3}}(k_i{}^2 agc/\nu)^{\frac{1}{3}}t/W \quad . \quad . \quad (9a)$$

In either form this is a first approximation to the time-temperature curve, and in it temperatures are measured in ° C., time in seconds, the physical constants in calorie units, W in cal. per 1° C. per sq. cm. The numerical values taken in determining the constant A were those appertaining to a temperature mid-way between T_0, the temperature of the bulk of the fluid, and T_B, the boiling point to which it is supposed the boundary rises. They were determined from experiments on spheres instead of flat plates, so that the actual numerical value of A may need revision when data for flat plates become available.

(4) Conclusion.

The equations so far deduced are expressed in a form appropriate to a thin plate, of which the surface and mean temperatures are indistinguishable. If, however, equations (9) or (9a) are differentiated with respect to time, we have:

$$W\frac{dT_s}{dt} = -0.0015(T_B - T_0)^{\frac{1}{3}}(k_i{}^2 agc/\nu)^{\frac{1}{3}} \quad . \quad . \quad . \quad (10)$$

In this form, the equation gives the heat loss per second per unit area from a flat body, and must be equally applicable to a massive one, in which T_s moves only slowly (the heat flow being adjusted by alteration of the temperature gradient within the body), as to a thin one (in which the heat loss results in a cooling of the whole), since the heat loss from a body of which the surface temperature is T_s cannot depend on conditions interior to that surface.

(5) *Alphabetical List of Symbols used.*

A a constant.

a coefficient of expansion of liquid.

B a constant (approx. $0 \cdot 0015$).

c specific heat of liquid.

d diameter of cylinder.

E thermal emissivity of solid.

g acceleration due to gravity.

h thickness of vapour film.

H heat loss per unit area per second.

k_l thermal conductivity of liquid.

k_v thermal conductivity of vapour.

L latent heat of vaporisation of liquid.

m mass of vapour per unit area.

M molecular weight of fluid.

ν kinematic viscosity of liquid.

n a constant (approx. $\frac{1}{3}$).

p pressure of vapour.

ρ density of vapour.

R the gas constant.

σ Stefan's radiation constant.

t time.

t_0 time at which $h = 0$.

T temperature.

T_0 temperature of bulk of liquid.

T_B boiling point of liquid.

T_s surface temperature.

T_s' initial value of T_s.

T_v temperature of vapour.

T' mean between T_0 and T_B.

θ temperature difference between solid and liquid.

V volume per gramme-molecule of vapour.

W heat capacity of solid per unit area.

z distance within fluid from solid boundary.

THE LONGITUDINAL RIDGED STRUCTURE IN THE TIN COATING OF TINPLATE.*

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(Figs. 3 to 6 = Plate XVII.)

SUMMARY.

The characteristics of the longitudinal ridge structure in the tin coating of tinplate are described. It is pointed out that similar structures can occur when liquids other than molten tin are spread on solid surfaces by means of rollers. A physical explanation of the mechanism of formation of the ridge structure is advanced, and this shows that the ridged structure should only arise when the rollers are wetted by the liquid.

It is concluded that the use of non-wetting grease-pot rollers would result in suppression of the ridged structure in tinplate. This has been verified in an experimental tinning machine.

IN a previous publication one of the authors [1] described a structure in the coating of tinplate consisting of a series of straight or branched ridges lying approximately parallel to the direction of tinning. Some preliminary observations were recorded by Macnaughtan in a paper read before the 18e Congrès de Chimie Industrielle, Nancy, 1938. [2] A typical longitudinal ridged structure photographed by the reflection method was shown in Fig. 14 of the former paper.[1] These periodic variations of the thickness of the tin coating affect the number of pores present,[1] and their existence is thus of practical importance.

Observations of the tinning process and examination of finished tinplate show that : (a) The ridges arise from runnels of tin which are established at the top pair of rolls in the grease pot and persist in similar positions on the sheet and on the rolls during the passage of the sheet ; (b) with thicker coatings the ridges are more widely spaced ; those for example on a plate carrying 14 lb. per basis box may be over $\frac{1}{2}$ in. apart, whereas the spacing is about 0·1 in. on an ordinary coke plate ; (c) provided the coating thickness is reasonably constant, increased speed reduces the spacing of the ridges ; (d) the spacing increases as the temperature of tinning is raised ; (e) with thin coatings the ridges have a greater tendency to form " branches " ; (f) grease lines,[1] when present, are almost exactly coincident with the ridges.[3]

The unevenness of the tin coating is found quantitatively by

* Received April 4, 1941.

examination of the variation of coating thickness across the sheet at right angles to the direction of tinning. A typical result obtained by the magnetic method [4] is shown as a profile in Fig. 1. The
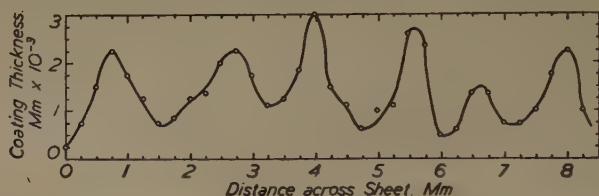
Fig. 1.—Unevenness of the Tin Coating, determined by the magnetic method.

added thickness of tin in the ridge appears to be relatively independent of the mean coating thickness. *See* Table I.

TABLE I.—*Tin Coating Thickness.*

0·0000606 in. thickness corresponding to 1 lb. per basis box.

Summit of Ridge. In.	Base of Ridge. In.	Difference. In.
0·000102	0·000047	0·000055
0·000136	0·000052	0·000084
0·000186	0·000098	0·000088
0·000300	0·000205	0·000095

Experimental Work with Red Lead Paste and Petroleum Jelly.— It was found that a similar ridge structure arises when other liquids are spread on solid surfaces by means of rollers; this made it possible to examine the phenomenon using substances fluid at room temperature, and, for convenience, on the surfaces of two rollers running idle.

The first experiments were carried out with a paste of linseed oil and red lead, but later ordinary yellow petroleum jelly was preferred. Two machines were used; the first a small tinning machine of usual design with the steel rollers approximately 14-in. body length by 3 in. in dia., driven by pinions. The second machine, built specially for the investigation, consisted essentially of two steel rollers, 5 in. in body length by 4 in. in dia., highly polished and chromium-plated. The rolls were driven by means of a central worm engaging with worm-wheels on each roller neck, variable speed being provided by cone pulleys. The distance between the rollers could be set at any fixed maximum by sliding bearings actuated by graduated fine-pitch screws.

The most obvious characteristic of the ridged structure is the spacing of the ridges, and a series of experiments was carried out to ascertain the effect on the spacing of variation of speed and

PLATE XVII.

Fig. 4.—Decrease of Ridge Spacing; rollers set closer.

Fig. 6.—Photograph through Glass Plate on which Ridges are Forming. Natural size.

Fig. 3.—Widely Spaced Ridge Structure.

Fig. 5.—"Branched" Ridge Structure. Natural size.

distance apart of the rollers.   The rollers were set fairly wide apart and thickly coated with petroleum jelly.   The machine was started and the rollers were brought slowly together until the ridge structure became definite.   At this stage the ridges were usually about ⅓ in. apart.   Each structure was allowed to persist for about 5 sec.; the spacing was then measured and the rollers were moved closer together.   Results are plotted in Fig. 2 and show that the spacing
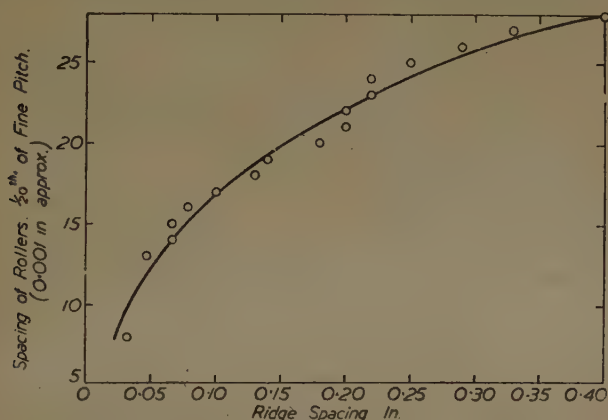
FIG. 2.—Relation of Ridge Space to Roller Setting.

diminishes as the rollers approach each other.   The speed of the rollers was also found to affect the spacing of the ridges, higher speeds decreasing the spacing.   Ridge structures developed in petroleum jelly are shown in Figs. 3 to 6.

Discussion.

The experiments and observations described above show that the ridged structure is produced when a rolling action takes place between two cylindrical surfaces, or one cylindrical and one plane surface, separated by a liquid which wets both surfaces forming a meniscus in the neighbourhood of the line of closest approach.   The structure also appears when two plane surfaces inclined to each other at a small angle contain a liquid meniscus near the line of intersection of the two planes, and the angle between the planes is increased.

The common feature in these two variations of the process is the tendency to produce a negative pressure or triple tensile stress in the liquid.   This negative pressure causes a pressure difference between the liquid and the air which is in contact with it.   The movement of liquid resulting from this pressure difference is, as will be shown, responsible for the ridged structure.   The following

explanation of the origin and persistence of the ridged structure is proposed.

Consider the forces acting on the surface of the liquid at a region where a slight irregularity of shape exists in the meniscus between two plane surfaces. The central section of the meniscus is represented in Fig. 7. When a negative pressure is set up by separation
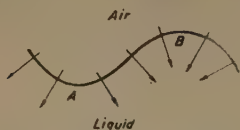
FIG. 7.—Forces Acting on the Surface of the Liquid where the shape of the meniscus between the plane surfaces is slightly irregular.
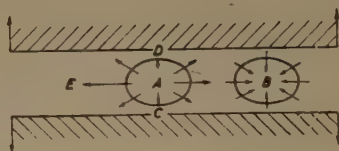
FIG. 8.—The Meniscus as seen from above.

of the two bounding surfaces, a resultant force will act in a direction perpendicular to the surface at each point, because a hydrostatically applied force can only act perpendicularly to the surface. The liquid at each point will tend to move in the directions indicated by the arrows in Fig. 7, and as a result of the divergence from A and the convergence towards B, the surface will move more rapidly at A than at B.

Now consider the meniscus as viewed from above (Fig. 8). Let the region A be a depression below the undisturbed level of the meniscus, and B an elevation. The horizontal components of the forces are shown by arrows. These forces come into operation as soon as the negative pressure is produced. It will be seen that the region A will fall more rapidly than the region B, and that lateral movement of liquid will take place. Thus in effect, owing to the proximity of the bounding surfaces, liquid is squeezed out of the regions C and D, the excess moving towards B and E. The negative pressure is therefore relieved by movement of air into the region A and of liquid from A to B and E.

It is next necessary to consider the origin of the periodic spacing of the ridges, and to show how this depends on the factors operating. The formation of a series of ridges can be represented as follows. Suppose that a chance disturbance causes a hollow in the meniscus at Q (Fig. 9 (a)) as the separation of the surfaces commences. This will cause liquid to move along the lines of direction of the forces, indicated by arrows. The arrows converge in the regions P and R, diverge at Q and are parallel at S and T; the regions P and R will therefore not fall as rapidly as S, Q and T. The result will be as shown in Fig. 9 (b). This in turn causes a divergence of arrows at U and V, with the result indicated in Fig. 9 (c). This continues until the process has reached the ends of the available space (Fig.

9 (d)). The spacing of the ridges depends on the lateral distance that the liquid can move during the time available. Thus an exceedingly slow separation of the solid surfaces with a liquid of low viscosity and large volume would permit the stabilising surface tension and gravitational forces to maintain a uniform meniscus without any lateral flow. As the speed or the viscosity are increased the relative effect of gravity is reduced, and a point is reached when the uniform meniscus is no longer stable. Lateral movement of the type illustrated above then becomes necessary. It can be seen that the spacing of the ridges will depend on the distance between the solid surfaces at the meniscus (or on the angle and the quantity of liquid present), the two increasing together. High viscosity will tend to reduce the spacing, and high speed of separation will have the same effect.
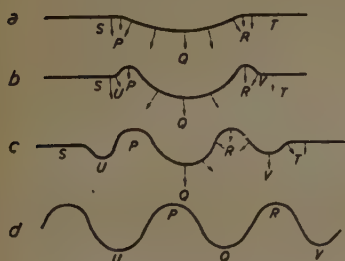
FIG. 9.—Formation of a Series of Ridges.
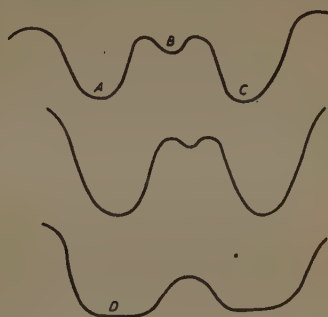
FIG. 10.—Ridges formed sufficiently far apart to be independent.

In some cases the ridges are formed so far apart that they persist as fully independent ridges. In other cases a tendency towards coalescence of neighbouring ridges is observed. This causes the familiar " branched " appearance, and can be explained as follows. Suppose that three hollows are not equally deep (A, B and C, Fig. 10); the shallower hollow B will tend to disappear, as it moves more rapidly than A and C. This will cause two ridges to run together, leaving the hollow A larger than the dynamic conditions permit. A new ridge will form at D owing to the absence of the lateral pressure component.

The theory proposed above is supported by observation during the process of tinning and examination of finished tinplates. The spacing of the tin ridges increases with the coating thickness (Fig. 11). In plates tinned at high speeds a branched structure of narrowly spaced ridges is usually observed. It will be recognised that the effect of speed is reduced by the fact that increase of speed causes more fluid to pass through the nip.[1] The direct effect of increased speed is to reduce the spacing; this may be partly counteracted by the associated effects on coating thickness.
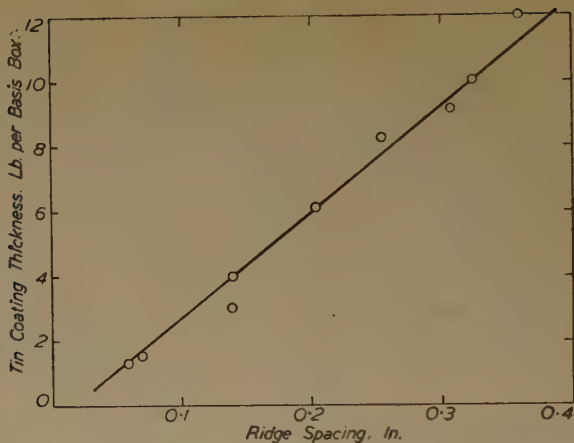
FIG. 11.—Spacing of Tin Ridges on Commercial Tinplates.

Suppression of the Ridge Structure.—In cases where the liquid fails to wet one or both of the surfaces, the conditions are different. The shape of the meniscus is illustrated in Fig 12. In this case the movement of the meniscus is not opposed by the fact that the liquid
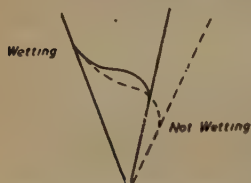
FIG. 12.—Shape of the Meniscus.

wets the surfaces; in addition, the profile of the meniscus is convex instead of concave, and so the pressure is exerted in such a direction that liquid moves towards the centre of the meniscus from one or both sides. This does not permit chance depressions of the surface to become stabilised.

In order to confirm the hypothesis that the use of rollers not attacked and wetted by molten tin would result in the suppression of the longitudinal ridged structure, a pair of chromium-faced rollers [5] has been installed on an experimental tinning machine in these laboratories. The machine, which has other novel features, will be fully described elsewhere. Preliminary observations show that with a pair of non-wetting rollers fitted in place of the usual pair at the top of the grease pot, the longitudinal ridge structure is eliminated, with consequent improvement of the appearance and continuity of the coating.

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(5) British Patent No. 496,402.

THE INFLUENCE OF THE STEEL-BASE COMPOSITION ON THE RATE OF FORMATION OF HYDROGEN-SWELLS IN CANNED-FRUIT TINPLATE CONTAINERS.—PART II.*

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SYNOPSIS.

Further statistically planned canning experiments of the type described in Part I. of this series of papers have been carried out with a pack of Czar plums in double-lacquered cans, and with packs of white cherries, gooseberries, Pershore plums and prunes in plain cans. It is shown that for such packs of Czar plums and gooseberries, cans made from low-phosphorus/high-copper steel base, recommended in Part I. for six other packs, are to be preferred from the point of view of hydrogen-swell formation, and that the cathodic efficiency of the steel for hydrogen evolution has a significant influence on the rate of swell-formation for such packs of cherries, gooseberries and prunes.

Two new types of corrosion test for steel base are described : The first, consisting of immersion in actual fruit juice, gives very poor correlation with the rate of hydrogen-swell formation within a can; the second, consisting of a very short immersion in boiling dilute hydrochloric acid, gives surprisingly good correlation. Reasons for these results are advanced, and the design of a rational steel-base test is discussed.

Differences between lacquered- and plain-can packs, and between fruits, are discussed in the light of the present and previous work.

I.—INTRODUCTION.

THIS paper is a direct continuation of Part I. recently published under the same title.[1] In order to avoid repetition it will be assumed that the reader is familiar with Part I., and able to refer to it. For clarity of reference, the numbers of the Fig. and Tables in Part II. are continued serially from those of Part I.

The results now reported refer to packs of Czar plums in lacquered cans, and sweet white cherries, gooseberries, yellow Pershore plums and prunes in plain cans. As before, storage tests of cans have been correlated statistically with chemical analyses and corrosion tests (in citric acid) of the steel base. Also, additional corrosion tests in fruit juices and in hydrochloric acid have been made for

the steel bases from the pack of Czar plums and the previously reported packs of raspberries and strawberries.

<div align="center">II.—EXPERIMENTAL TECHNIQUES.</div>

(1) *General.*

The tinplate sample from which the cans were drawn was the same as that used in Part I., and all general procedures of can manufacture, fruit packing and storage, chemical analysis and corrosion tests were carried out as there described.

(2) *Packing and Storage of Fruit.*

As well as the main packs, three additional cans were packed with each fruit and stored at room temperature for one month; they were then examined for vacuum, headspace, hydrogen-ion concentration and total acidity. The mean results are given in Table XVI., which supplements Table I. of Part I. They may be taken as representative of the can contents in each main pack.

<div align="center">TABLE XVI.—*Particulars of Can Contents.*</div>

Fruit.	Headspace. Ml.	Vacuum. Cm. Hg.	pH (by Quinhydrone Electrode).	Acidity (Citric Acid). %.
Czar plums (lacquered cans) .	46	30	3·07	0·70
White cherries (plain cans) .	47·5	30	4·40	0·12
Gooseberries (plain cans) .	39	33	2·89	1·12
Pershore plums (plain cans) .	46·5	31	3·03	0·84
Prunes (plain cans) . .	48	30	4·10	0·32

The rate of loss by hydrogen-swell formation, for the main packs at 35° C., compared with the average of standard tests (at 35° C.) previously made at Campden, is given in Table XVII., which

<div align="center">TABLE XVII.—*Rate of Formation of Hydrogen-Swells.*</div>

Fruit.	Test.	Time, Weeks, to reach loss of—		
		15%.	25%.	50%.
Czar plums (lacquered cans)	This test	17	20	28
	Previous average	...	...	...
White cherries (plain cans)	This test	77	86	94
	Previous average	28	30	36
Gooseberries (plain cans)	This test	42	45	64
	Previous average	51	56	66
Pershore plums (plain cans)	This test	49	66	76
	Previous average	50	58	75
Prunes (plain cans)	This test	11	16	19
	Previous average	17	19	22

supplements Table II. of Part I. The only batch of fruit showing somewhat unusual behaviour was that of cherries.

(3) *Fruit-Juice Corrosion Tests.*

In Part I. it was suggested that corrosion tests of the steel base in actual fruit juices might well give better correlation with canning tests than did the citric-acid corrosion tests there reported. Consequently, as well as the two standardised corrosion tests of steel base in citric acid, carried out on each can body as described in Part I., tests of the steel base in actual fruit juice have now been made for the pack of Czar plums and for the previously reported packs of raspberries and strawberries. For this purpose, a small strip of tinplate (about 6 × 1·5 cm.) was taken from the body of each can in the above three packs and detinned in the usual way with acidified antimony chloride, the thin film of tin-iron compound being then removed with 1FF emery cloth in the standard manner. Specimens 5 × 1 cm. were cut from this strip, degreased, weighed, pickled for 2 min. exactly in boiling 11% hydrochloric acid, washed, dried and re-weighed. This pickling was resorted to in order to remove the abraded metal on the surface of the specimen, since it was desired to have the steel in as " natural " a condition as possible for the subsequent fruit-juice tests; and it has led incidentally to a value (for each specimen) for the weight-loss in 2 min. in boiling dilute hydrochloric acid, which has proved of great interest (*vide infra*). The pickled specimens were sterilised in hot alcohol, after weighing.

The fruit juices used were from the same batches of fruit as used in the main can packs; they were obtained from part of the batch processed in glass containers at the same time as the main packs, by draining and expressing the fluid. Test-tubes 15 cm. long × 1·5 cm. internal dia., containing 15 ml. of fruit juice, were plugged with cotton-wool and sterilised at 100° C. for 35 min.; they were then cooled to 25° C. A sterilised steel specimen was quickly inserted in each, and the cotton-wool plug was replaced; the specimens were kept for 72 hr. at 25° C., and then rinsed, dried, degreased and re-weighed.

III.—EXPERIMENTAL RESULTS AND STATISTICAL ANALYSIS.

(1) *Numerical Results.*

The numerical results of storage, chemical analysis and corrosion tests of packs of Czar plums in double-lacquered cans, and of cherries, gooseberries, Pershore plums and prunes in plain cans, are given in Tables XVIII. to XXII. In addition, the results of hydrochloric-acid pickling and fruit-juice corrosion tests for the same pack of Czar plums and for the packs of raspberries and strawberries other results of which are reported in Part I. (Tables VIII.

and IX.) are given in Table XXIII. In these Tables the following symbols are used :

T = Time of formation of hydrogen-swell at 35° C. (weeks).

S = Sulphur
P = Phosphorus } content of steel base (for convenience in printing ex-
Cu = Copper } pressed as parts per 100,000, *i.e.*, 66 = 0·066%).

M = Weight loss of corrosion specimen 7·5 × 2·5 cm. under '' closed '' conditions (mg. per 72 hr.).

H = Weight loss of corrosion specimen 3·5 × 2·5 cm. under '' open '' conditions (mg. per 72 hr.).

E = Corrosion potential of corrosion specimen under '' open '' conditions (mV., against hydrogen electrode in 0·1-M. citric acid; add −117 mV. for normal hydrogen scale).

ΔE = '' Cathodic Increment '' of corrosion specimen under '' open '' conditions (mV.).

A = Weight loss of specimen 5 × 1 cm. during acid pickling (mg. per 2 min.).

F = Weight loss of specimen 5 × 1 cm. under ''fruit-juice'' conditions (mg. per 72 hr.).

(2) *Mean Composition of Tinplate Sample.*

The additional results now available make possible a slight revision of the mean chemical analysis of the tinplate sample used in this research, and hence of the description of the population from which it was drawn. Thus Table X. of Part I. is superseded by Table XXIV.

It may be noted that the amended figures differ only very slightly from the original, although for each element a further 304 analyses have been added to the original 392. This promotes confidence in the methods of sampling and chemical analysis.

(3) *Correlation of Time of Formation of Hydrogen-Swell with Steel-Base Corrosion in Citric Acid.*

Scatter diagrams of the time of formation of hydrogen-swell, T (weeks), and the weight-loss, M (mg. per 72 hr.), of a 7·5 × 2·5 cm. specimen of the steel base of the can body in 0·5% citric acid, under '' closed '' conditions, are given in Part I. for 7 packs. It is thought unnecessary to give the 5 similar diagrams for the present packs. The correlation coefficients r_{TM} are given in Table XXV. (cf. Table XI. of Part I.), with the probabilities p that the values are due to chance. In this Table (and in Tables XXVI.–XXIX. those correlation coefficients that are significant (strong probability, $p < 0.05$) are underlined, and those that are very significant (practical certainty, $p < 0.01$) are in heavy type.

Evidently in the cases of gooseberries and prunes in plain cans a short time of formation of hydrogen-swell is significantly associated with a rapid '' artificial '' corrosion-rate of the steel base of the can body; and if it had been experimentally possible to take the bottom end of the can also into account, the correlations would doubtless have been still greater. The non-significance of r_{TM} for

TABLE XVIII.—*Czar Plums.* (*Lacquered Cans.*)

No.	Storage. T.	Analysis.			Corrosion.			
		S.	P.	Cu.	M.	H.	E.	ΔE.
1	15	61	54	96	207	234	—223	— 2
	28	74	63	100	194	172	—213	+ 2
2	28	61	56	105	187	86	—199	+ 2
	32	62	59	102	202	225	—220	0
3	24	84	59	85	198	154	—211	+ 2
	35	81	57	85	95	56	—189	+ 1
4	20	84	64	56	193	232	—218	+ 3
	29	77	70	53	169	247	—226	— 4
5	22	63	37	126	107	57	—193	— 3
	46	57	30	128	77	50	—182	+ 5
6	23	91	73	160	128	88	—194	+ 7
	28	83	68	160	115	69	—194	+ 1
7	35	47	26	156	73	42	—183	— 4
	36	59	34	104	93	50	—189	— 2
8	35	46	49	78	226	146	—209	+ 3
	36	40	47	50	138	78	—198	0
10	17	41	50	129	114	67	—184	+11
	18	40	54	108	143	64	—186	+ 8
11	15	91	85	95	243	332	—229	— 1
	17	76	66	73	257	406	—226	+ 6
12	15	57	86	46	181	239	—220	+ 2
	23	54	78	50	230	266	—214	+10
13	17	75	76	139	167	126	—206	+ 3
	27	80	83	82	222	306	—223	+ 3
14	12	85	84	81	227	281	—227	— 2
	17	76	86	146	152	92	—201	+ 1
15	20	56	52	44	188	145	—210	+ 2
	26	45	48	44	132	96	—203	0
16	38	57	38	101	82	56	—182	+ 8
	45	59	41	102	132	101	—202	+ 2
17	34	66	59	52	226	216	—221	— 1
	36	88	66	82	179	120	—207	+ 1
18	32	54	48	106	184	218	—219	+ 1
	38	51	32	150	72	48	—179	+ 6
19	20	40	29	218	49	31	—146	+11
	29	34	15	232	61	56	—195	— 5
20	26	53	54	74	210	191	—213	+ 4
	35	50	52	82	153	98	—202	+ 2
21	34	57	62	72	153	103	—205	0
	35	58	61	61	150	102	—207	— 3
22	32	74	69	115	153	198	—221	— 3
	38	71	71	114	185	147	—206	+ 6
23	16	69	56	91	125	102	—209	— 4
	22	93	69	84	165	105	—205	0
24	30	98	85	82	178	207	—217	+ 2
	37	72	68	95	196	147	—210	+ 2
25	17	78	68	73	230	303	—224	+ 2
	20	100	81	79	104	94	—199	+ 4
26	24	81	75	82	172	117	—201	+ 7
	58	81	73	83	196	182	—214	+ 2
29	22	38	35	79	69	46	—162	+21
	28	19	45	10	273	402	—220	+12
31	22	29	25	26	244	142	—206	+ 5
	23	33	29	29	241	280	—227	— 2
32	35	44	20	241	109	59	—195	— 3
	40	44	20	242	89	45	—173	+ 9

TABLE XIX.—*Sweet White Cherries.* (*Plain Cans.*)

No.	Storage. T.	Analysis.			Corrosion.			
		S.	P.	Cu.	M.	H.	E.	ΔE.
1	103	35	37	121	118	63[*]	—193	0
	118	81	31	105	176	153	—214	— 1
2	94	66	55	130	162	125	—211	— 2
	120	74	59	117	119	75	—196	+ 1
3	86	75	50	106	158	144	—211	+ 1
	91	77	54	84	85	86	—207	— 7
4	94	71	65	57	173	126	—211	— 2
	118	74	62	72	156	100	—208	— 4
5	80	64	39	134	124	79	—201	— 3
	103	56	27	140	80	53	—187	+ 1
6	88	80	69	166	104	115	—209	— 2
	136	90	56	219	61	40	—177	— 2
7	86	59	29	107	101	61	—187	+ 5
	141	61	34	177	81	53	—191	— 3
8	105	49	48	85	183	168	—217	— 2
	120	45	47	61	161	109	—207	— 1
10	121	60	41	123	147	104	—201	+ 4
	126	52	36	122	122	92	—201	+ 1
11	80	80	70	74	244	221	—216	+ 4
	103	72	74	68	259	359	—223	+ 7
12	67	55	82	48	251	446	—228	+ 7
	111	50	48	49	162	92	—206	— 4
13	86	65	61	75	218	312	—224	+ 3
	123	90	77	122	125	79	—195	+ 4
14	67	78	77	80	229	311	—218	+ 9
	118	74	68	84	205	245	—219	+ 3
15	88	54	50	49	128	260	—225	— 2
	102	53	52	50	203	201	—217	+ 1
16	93	65	40	101	105	64	—193	0
	93	66	45	99	108	68	—191	+ 4
17	77	68	85	128	292	471	—217	+19
	93	79	113	80	197	173	—208	+ 7
18	82	58	36	181	43	43	—179	+ 1
	93	51	59	98	153	87	—193	+ 8
19	54	50	46	116	118	73	—192	+ 5
	91	40	38	124	69	80	—199	0
20	130	56	55	77	216	214	—220	— 1
	132	59	56	74	170	101	—205	— 1
21	114	50	54	77	218	244	—219	+ 3
	114	57	57	79	207	195	—215	+ 3
22	103	82	69	88	134	146	—213	— 2
	110	73	65	83	120	71	—195	+ 1
23	93	64	61	84	199	145	—207	+ 5
	94	65	66	100	139	83	—200	0
24	82	79	69	81	182	144	—209	+ 3
	110	81	75	81	146	148	—215	— 3
25	77	77	71	91	193	166	—213	+ 2
	113	71	65	83	206	210	—217	+ 2
26	112	75	68	79	123	83	—201	— 1
	130	71	64	85	160	133	—199	+11
29	65	33	16	130	86	40	—173	+ 2
	67	35	12	135	62	44	—172	+ 9
31	40	23	58	19	227	337	—226	+ 2
	73	25	47	14	296	492	—220	+17
32	125	47	12	259	112	67	—197	— 2
	131	49	17	262	81	44	—179	+ 2

TABLE XX.—*Gooseberries.* (*Plain Cans.*)

No.	Storage. T.	Analysis.			Corrosion.			
		S.	P.	Cu.	M.	H.	E.	ΔE.
1	70	61	57	100	140	95	−205	− 2
	70	60	59	101	118	72	−201	− 5
2	45	65	60	98	165	93	−204	− 2
	63	35	35	112	151	104	−199	+ 6
3	28	87	60	86	214	234	−224	− 2
	63	85	59	103	90	72	−191	+ 5
4	32	71	62	53	213	278	−225	0
	49	81	75	58	141	98	−203	+ 1
5	53	64	39	127	93	48	−181	+ 4
	62	63	34	136	87	52	−192	− 3
6	50	89	78	165	81	53	−185	+ 3
	78	49	35	196	67	37	−176	− 6
7	75	47	30	167	74	44	−181	0
	75	48	24	155	79	52	−185	+ 3
8	75	58	61	82	115	66	−196	− 2
	77	52	54	75	134	61	−197	− 5
10	72	66	72	135	112	77	−187	+11
	73	62	61	82	181	192	−217	0
11	42	75	70	69	258	391	−227	+ 5
	42	63	59	79	243	352	−227	+ 2
12	39	51	83	51	281	499	−221	+15
	42	51	81	51	224	363	−220	+10
13	42	74	71	108	140	141	−211	0
	64	59	63	76	209	112	−212	− 5
14	37	68	74	81	243	346	−224	+ 5
	42	64	69	72	218	260	−224	+ 1
15	64	52	44	47	178	103	−199	+ 6
	77	58	61	49	218	195	−217	+ 1
16	90	62	39	100	93	132	−215	− 5
	90	68	42	101	80	80	−201	− 2
17	45	66	106	76	200	129	−198	+11
	50	67	81	68	186	230	−215	+ 6
18	71	53	38	168	79	44	−189	− 8
	74	43	42	144	131	87	−198	+ 3
19	78	59	41	164	143	87	−200	+ 1
	78	47	49	121	135	93	−204	− 2
20	68	57	61	71	167	83	−197	+ 3
	78	46	47	65	210	182	−215	+ 1
21	74	55	55	60	184	239	−222	0
	78	58	62	75	204	154	−215	− 2
22	68	85	73	85	95	68	−196	− 1
	77	85	69	80	106	76	−201	− 3
23	45	67	64	89	192	109	−199	+ 7
	69	60	61	87	138	204	−212	+ 8
24	36	78	73	86	179	144	−212	0
	37	74	71	82	129	79	−201	− 2
25	71	75	71	86	192	180	−217	− 1
	75	71	60	78	200	179	−216	0
26	44	68	70	84	140	95	−200	+ 3
	54	75	71	83	134	90	−192	+10
29	53	37	12	127	93	37	−158	+12
	69	36	4	126	94	59	−181	+10
31	47	30	27	32	191	99	−200	+ 4
	69	23	48	12	259	373	−225	+ 5
32	60	45	15	242	98	45	−176	+ 6
	62	42	8	244	112	59	−192	− 1

TABLE XXI.—*Yellow Pershore Plums.* (*Plain Cans.*)

No.	Storage T.	Analysis			Corrosion			
		S.	P.	Cu.	M.	H.	E.	ΔE.
1	69	75	60	94	165	114	−209	− 2
	75	59	53	102	147	78	−191	+ 7
2	76	67	57	86	146	82	−194	+ 5
	78	60	56	99	145	84	−197	+ 3
3	41	78	49	92	58	39	−175	− 1
	68	87	58	94	128	71	−194	+ 2
4	33	71	61	68	222	344	−229	0
	37	77	60	73	221	194	−219	− 2
5	70	62	40	127	115	74	−197	0
	75	58	34	95	54	48	−181	+ 4
6	79	108	72	167	119	129	−209	0
	84	68	50	196	44	47	−188	− 4
7	74	65	40	158	97	57	−188	+ 3
	78	55	35	176	85	50	−179	+ 7
8	80	47	51	47	193	292	−227	− 1
	84	46	50	56	182	300	−226	0
10	78	58	39	111	116	57	−185	+ 5
	86	58	49	114	132	64	−191	+ 3
11	79	55	42	106	88	111	−210	− 4
	79	63	45	110	72	69	−198	− 3
12	66	55	60	93	82	69	−197	− 2
	76	64	86	86	197	62	−185	+ 8
13	49	65	70	74	242	425	−229	+ 5
	70	76	74	91	198	168	−213	+ 2
14	39	60	58	83	202	103	−203	+ 2
	78	69	60	102	210	168	−214	+ 1
15	76	54	54	46	212	126	−199	+10
	86	36	41	45	213	153	−214	− 1
16	88	62	39	104	137	89	−199	+ 2
	90	64	40	102	112	76	−197	+ 1
17	49	73	104	76	226	376	−215	+16
	67	71	105	77	187	226	−214	+ 7
18	66	52	56	71	157	155	−213	0
	75	78	62	91	122	186	−212	+ 5
19	88	75	65	129	125	89	−201	0
	88	46	29	187	76	46	−184	− 1
20	84	52	53	85	181	223	−219	+ 1
	86	54	57	73	174	138	−209	+ 2
21	51	66	68	77	196	223	−217	+ 3
	73	61	62	60	191	117	−207	+ 1
22	74	80	76	85	113	80	−191	+ 8
	79	84	75	88	126	214	−222	− 3
23	76	69	54	78	184	69	−191	+ 4
	84	74	58	75	230	294	−229	− 3
24	75	82	70	77	182	123	−205	+ 4
	79	81	73	94	182	207	−218	+ 1
25	47	92	83	78	140	138	−209	+ 2
	79	60	60	79	196	255	−223	0
26	68	79	75	78	163	116	−206	+ 1
	73	85	74	84	193	162	−214	0
29	48	34	17	126	103	52	−179	+ 9
	53	38	7	138	106	60	−184	+ 8
31	63	41	68	12	254	413	−229	+ 4
	65	20	50	16	288	443	−208	+26
32	77	47	17	236	115	64	−191	+ 2
	80	46	20	241	93	72	−204	− 8

TABLE XXII.—*Prunes.* (*Plain Cans.*)

No.	Storage. T.	Analysis.			Corrosion.			
		S.	P.	Cu.	M.	H.	E.	ΔE.
1	20	67	55	105	199	192	−217	0
	21	75	62	97	198	192	−215	+ 2
2	19	53	46	110	133	79	−203	− 4
	27	64	43	140	94	86	−199	+ 1
3	14	78	59	93	172	188	−211	+ 6
	23	78	55	98	147	80	−192	+ 7
4	16	78	65	58	163	134	−215	− 5
	23	82	65	66	203	243	−224	− 2
5	16	66	42	133	126	86	−203	− 4
	21	63	41	132	99	51	−181	+ 6
6	16	104	79	164	151	119	−208	0
	27	71	47	208	54	39	−176	− 3
7	16	46	29	150	113	67	−195	0
	19	54	34	162	109	79	−199	0
8	20	49	41	80	161	139	−215	− 4
	23	51	53	76	218	259	−224	− 1
10	31	63	43	127	111	64	−194	− 1
	36	54	37	124	101	67	−195	− 1
11	19	60	54	69	203	143	−212	0
	27	57	58	60	170	127	−213	− 5
12	17	53	83	50	279	437	−218	+16
	28	64	60	107	99	73	−202	− 5
13	27	73	70	80	172	207	−222	− 3
	27	84	71	12⊅	149	151	−217	− 4
14	14	78	60	107	167	194	−217	+ 1
	18	75	69	92	211	236	−219	+ 2
15	17	62	56	50	197	120	−209	− 1
	27	53	54	49	156	155	−218	− 5
16	34	74	47	135	97	54	−183	+ 6
	38	67	41	110	104	57	−189	+ 1
17	16	78	107	68	186	245	−215	+ 7
	16	91	100	94	190	234	−213	+ 8
18	8	58	52	84	165	84	−194	+ 6
	23	60	81	155	152	111	−207	− 1
19	11	69	58	123	101	72	−195	+ 1
	21	56	48	122	126	76	−197	+ 1
20	17	57	60	72	192	172	−216	− 1
	22	56	54	68	218	226	−220	+ 1
21	11	60	58	91	169	174	−213	+ 3
	17	48	54	65	203	252	−221	+ 2
22	24	80	68	93	131	87	−201	0
	27	86	69	89	101	87	−205	− 4
23	8	59	50	52	186	105	−200	+ 5
	18	87	60	89	197	180	−216	0
24	24	79	71	84	185	252	−222	+ 1
	33	84	74	89	126	115	−211	− 4
25	8	87	76	83	131	122	−206	+ 3
	15	94	80	81	138	124	−211	− 2
26	8	79	74	85	179	174	−216	− 1
	34	80	69	88	76	95	−205	− 2
29	16	39	15	130	114	63	−189	+ 4
	27	34	13	135	61	52	−187	+ 1
31	18	30	30	31	232	196	−221	− 3
	20	27	58	18	279	359	−218	+12
32	8	47	20	247	131	69	−185	+10
	11	47	18	222	106	65	−193	+ 1

TABLE XXIII.—*Acid and Fruit-Juice Corrosion Tests.*

No.	Raspberries.		Strawberries.		Czar Plums.	
	A.	F.	A.	F.	A.	F.
1	56	19	73	24	97	28
	79	20	81	25	89	44
2	107	30	27	11	112	28
	45	14	72	17	95	24
3	43	20	22	16	113	32
	45	21	28	18	37	11
4	134	34	64	29	79	17
	68	18	69	20	108	21
5	37	21	30	18	51	20
	38	18	40	15	31	19
6	25	39	96	21	99	37
	25	16	71	19	88	48
7	23	17	65	18	26	16
	33	15	43	14	26	12
8	127	45	67	19	130	26
	104	24	78	29	79	13
10	99	31	65	22	64	20
	67	20	40	22	54	16
11	143	51	117	14	168	29
	133	48	96	37	148	31
12	90	28	60	21	101	23
	112	27	87	28	176	32
13	137	36	120	35	120	16
	156	40	104	36	157	44
14	74	21	131	38	157	56
	60	23	63	25	100	46
15	159	32	76	26	148	22
	82	27	131	35	68	15
16	100	28	91	27	69	16
	80	16	92	21	99	19
17	122	34	121	27	107	31
	112	30	42	22	120	49
18	135	33	25	29	91	48
	127	28	62	30	20	12
19	98	24	64	17	25	39
	29	18	16	40	29	14
20	113	32	71	21	130	25
	88	24	130	25	96	18
21	146	29	101	25	87	17
	83	24	76	15	91	19
22	142	27	127	33	114	37
	144	35	55	19	104	27
23	121	30	80	28	136	22
	126	33	81	31	99	23
24	128	24	104	28	120	26
	143	32	94	25	155	29
25	77	25	91	25	147	30
	117	29	113	31	67	16
26	129	37	137	23	97	27
	115	38	96	26	130	57
29	56	14	17	19	24	15
	249	71	24	29	87	28
31	108	26	139	26	90	15
	124	17	60	12	130	26
32	18	17	28	10	27	16
	30	12	26	10	18	39

TABLE XXIV.—*Description of Tinplate Population.*

	Mean Content. %.	Standard Deviation. %.	Limits between which 95% of the Population lies. %.
Sulphur . . .	0·062	0·017	0·030–0·095
Phosphorus	0·054	0·018	0·018–0·090
Copper . . .	0·101	0·048	0·006–0·195

TABLE XXV.—*Correlation of Time of Formation of Hydrogen-Swell, T, with Steel-Base Corrosion under " Closed " Conditions, M.*

Fruit.	r_{TM}.	p.
Czar plums (lacquered cans) . . .	−0·255	$1·5 \times 10^{-1}$
Cherries (plain cans) . . .	−0·204	$2·5 \times 10^{-1}$
Gooseberries (plain cans) . . .	−0·446	$7·3 \times 10^{-3}$
Pershore plums (plain cans) . . .	−0·245	$1·6 \times 10^{-1}$
Prunes (plain cans) . . .	−0·347	$4·6 \times 10^{-2}$

the plum and cherry packs may well be partly due to the differences in composition between the body and bottom end of the can.

(4) *Correlation of Time of Formation of Hydrogen-Swell with Steel-Base Corrosion in* (a) *Fruit Juices,* (b) *Boiling Hydrochloric Acid.*

The time of formation of hydrogen-swell, T (weeks), has been correlated with the weight-loss, F (mg. per 72 hr.), of a 5×1-cm. specimen of the steel base of the can body in the appropriate fruit extract at 25° C., and with the weight-loss, A (mg. per 2 min.), of the same specimens during their previous pickling in boiling 11% hydrochloric acid. The correlation coefficients r_{TF} and r_{TA} are given in Table XXVI., together with the previously obtained values of r_{TM} and values of r_{FA} for comparison, for the three packs for which measurements of F and A have been made.

TABLE XXVI.—*Comparison of Correlations between Time of Formation of Hydrogen-Swell, T, and Steel-Base Corrosion in Fruit Juice, F, Hydrochloric Acid, A, and Citric Acid, M.*

Fruit.	r_{TF}.	r_{TA}.	r_{TM}.	r_{FA}.
Czar plums . . .	±0·000	−0·267	−0·255	+0·446
Raspberries * . . .	−0·332	−0·455	−0·406	+0·781
Strawberries * . . .	−0·114	−0·242	−0·225	+0·465

* Numerical results for M in Part I.

It is immediately clear from these results that the steel-base corrosion in fruit juice, F, so far from giving a better correlation with hydrogen-swell formation than does the steel-base corrosion in citric acid, M, in fact gives a worse; all the values of r_{TF} are smaller than the corresponding values of r_{TM}. On the other hand, the steel-base corrosion in hot hydrochloric acid in the pickling process gives *better* correlation with hydrogen-swell formation than either of the corrosion tests proper; all the values of r_{TA} are a little larger than the corresponding values of r_{TM}. This unexpected result may be accounted for by a consideration of the conditions of can corrosion. It is well known that the corrosion reaction between the can and fruit contents leads first of all to the removal of oxygen in the headspace with consequent increase of " vacuum," and there are good experimental and theoretical reasons for thinking that the rate of this reaction is much less influenced by the steel-base composition than is that of the subsequent hydrogen-evolution reaction that finally produces the hydrogen-swell. Consequently, the variation in the T values within a pack arises mainly from differences in rate of the hydrogen-evolution corrosion reaction. Now the F tests take place under conditions where oxygen has free access to the corroding system and where its absorption accounts for a good deal of the corrosion; but the A test is purely hydrogen-evolution corrosion, and the M test very nearly so, and on this account they correspond more nearly to the T test. The practical implication of the result is at once evident : That is, rapid (2 min.) tests of steel base in boiling dilute hydrochloric acid give as good an indication of the likely behaviour of tinplate in practice as do carefully controlled low-temperature corrosion tests in citric acid, while simple fruit-juice tests with oxygen present are useless for the purpose. This opens up new possibilities for the rapid testing of tinplate, based on a steel-base test in boiling dilute hydrochloric acid. It must be emphasised, however, that such a grading of tinplate would be valid *only* for packs that have previously been shown to give high values of the correlation coefficient r_{TA}—for example, lacquered-can packs of raspberries similar to that we have investigated.

The three values of r_{FA} are all significant, and are notably higher than the other coefficients discussed in this section. They indicate that the steel-base corrosion-rates in the fruit-juice test (F) and in the pickling test (A) are in part determined by factors common to both; and that F and A have more causative factors in common than have either T and A or T and F, since the respective coefficients are larger. It is very probable that these extra common factors are (1) the absence, in the F and A tests, of tin metal or ions, present in the T test; (2) the fact that F and A both use iron weight-loss as the criterion of corrosion, whereas the T test uses, in effect, the time taken for the production within the can of a standard amount of hydrogen; (3) the use of the same small

strip of metal in both F and A tests, which avoids the sampling errors that occur when either F or A are correlated with T, the value of which depends upon the attack on numerous small areas of metal in different parts of the can. These three extra common factors evidently outweigh the effect of the presence of oxygen on the F test and its absence in the A test.

(5) *Correlation of Time of Formation of Hydrogen-Swell with Steel-Base Composition.*

Table XXVII. gives the relevant total, and first- and second-order partial, correlation coefficients between the time of formation of hydrogen-swell, T, and the sulphur, phosphorus and copper contents of the can steel base, S, P and Cu respectively. It may be compared with Table XII. of Part I.; scatter diagrams of T against P, and T against Cu, comparable with those of Figs. 4 and 5 of Part I., being of less interest for the present packs, are omitted.

TABLE XXVII.—*Correlation of Time of Formation of Hydrogen-Swell*, T, *with Steel-Base Composition Variates, S, P and Cu.*

	Czar Plums (Lacquered Cans).	White Cherries (Plain Cans).	Goose-berries (Plain Cans).	Yellow Pershore Plums (Plain Cans).	Prunes (Plain Cans).
Total Correlation Coefficients.					
r_{TS}	−0·115	+0·278	−0·309	+0·100	+0·048
r_{TP}	−0·313	−0·093	−0·398	−0·188	−0·046
r_{TCu}	+0·150	+0·307	+0·236	+0·242	±0·000
r_{SP}	+0·761	+0·577	+0·650	+0·608	+0·595
r_{SCu}	−0·068	+0·059	−0·143	+0·024	−0·003
r_{PCu}	−0·379	−0·490	−0·564	−0·505	−0·435
First-Order Partial Correlation Coefficients.					
$r_{TS.P}$	+0·199	+0·407	−0·071	+0·019	+0·112
$r_{TS.Cu}$	−0·107	+0·273	−0·286	−0·109	+0·048
$r_{TP.S}$	−0·349	−0·322	−0·273	−0·161	−0·111
$r_{TP.Cu}$	−0·280	+0·070	−0·331	−0·078	−0·051
$r_{TCu.S}$	+0·144	+0·303	+0·203	+0·245	+0·001
$r_{TCu.P}$	+0·036	+0·301	±0·015	+0·173	−0·022
$r_{SP.Cu}$	+0·796	+0·696	+0·697	+0·719	+0·770
$r_{SCu.P}$	+0·368	+0·480	+0·356	+0·484	+0·462
$r_{PCu.S}$	−0·506	−0·643	−0·626	−0·655	−0·602
Second-Order Partial Correlation Coefficients.					
$r_{TS.PCu}$	+0·200	+0·314	−0·081	−0·076	+0·137
$r_{TP.SCu}$	−0·324	−0·175	−0·191	±0·000	−0·138
$r_{TCu.SP}$	−0·041	+0·132	+0·043	+0·188	−0·083

As in Part I., the purely metallurgical correlations between sulphur, phosphorus and copper contents appear, further fortifying the results then obtained; they are averaged for the previous and present results, and more fully discussed, in Section IV. (d) below.

The correlation of can-failure with the various metallurgical factors may now be considered.

(a) r_{TS}, $r_{TS.P}$, $r_{TS.Cu}$, $r_{TS.PCu}$.—The only significant value is $r_{TS.P} = + 0.407$ for cherries in plain cans. Thus, for this pack only, decrease of rate of can-failure (increase of T), is associated with increase of sulphur content of the steel base (within the limits of the population being investigated), when phosphorus content is constant and copper content varies naturally.

(b) r_{TP}, $r_{TP.S}$, $r_{TP.Cu}$, $r_{TP.SCu}$.—A significant negative value of r_{TP} is found only for gooseberries in plain cans; thus, for this pack only, increase of T is associated with decrease of phosphorus content, when sulphur and copper contents vary naturally. A significant negative value of $r_{TP.S}$ is found only for Czar plums; thus in this case increase of T is associated with decrease of phosphorus content when sulphur content is constant. We may note that in this case $r_{TP.SCu} = - 0.324$ and is scarcely significant; this indicates that the negative correlation found between T and P in $r_{TP.S}$ is partly due to small positive correlation between T and Cu, Cu and P being as usual strongly negatively correlated.

(c) r_{TCu}, $r_{TCu.S}$, $r_{TCu.P}$, $r_{TCu.SP}$.—Insignificant values are found. Thus increase of T is not associated with any particular copper content, whether or not sulphur and phosphorus contents are kept constant, for any of the five packs here reported.

We may put these results in a practical way: For packs of cherries in plain cans made from pack-rolled tinplate ($1\frac{1}{2}$ lb. of tin per basis box) as obtainable on the British market, it is very probable that tinplate made from steel bases having sulphur and copper contents higher than the average (phosphorus being constant) gives an incidence of hydrogen-swells slower than the average. For packs of gooseberries in plain cans and Czar plums in lacquered cans, steel bases low in phosphorus and high in copper, are similarly beneficial. For Pershore plums and prunes in plain cans, the sulphur, phosphorus and copper contents are immaterial.

(6) *Correlation of " Artificial " Corrosion-Rates of Steel Base with Steel-Base Composition and with Corrosion-Potential.*

In Part I., Figs. 6, 7, 8, 9 are scatter diagrams of M against P, M against Cu, H against Cu, and H against E, respectively. The present results add a further 304 points to each of these diagrams, in positions sufficiently well indicated by the original 392 points; no change in the form of the diagrams or deductions therefrom is produced, and it is thought unnecessary to reproduce amended diagrams.

(7) *Correlation of Cathodic Increment with Steel-Base Composition and with Time of Formation of Hydrogen-Swell.*

The relevant correlation coefficients, as calculated, are given in Table XXVIII., which may be compared with Table XIII. of Part I.

TABLE XXVIII.—*Correlation of Cathodic Increment, ΔE, with Steel-Base Composition Variates, S, P and Cu, and with Time of Formation of Hydrogen-Swell, T.*

	Czar Plums (Lacquered Cans).	White Cherries (Plain Cans).	Goose-berries (Plain Cans).	Yellow Pershore Plums (Plain Cans).	Prunes (Plain Cans).
Total Correlation Coefficients.					
$r_{T\Delta E}$	-0.077	-0.355	-0.362	-0.220	-0.349
$r_{S\Delta E}$	-0.255	-0.166	-0.187	-0.277	-0.153
$r_{P\Delta E}$	-0.076	$+0.234$	$+0.116$	$+0.154$	$+0.069$
$r_{Cu\Delta E}$	-0.009	-0.168	-0.148	-0.320	$+0.010$
First-Order Partial Correlation Coefficients.					
$r_{S\Delta E.P}$	-0.305	-0.379	-0.347	$-\mathbf{0.472}$	-0.281
$r_{S\Delta E.Cu}$	-0.256	-0.159	-0.213	-0.284	-0.153
$r_{P\Delta E.S}$	$+0.188$	$+0.409$	$+0.318$	$+0.423$	$+0.248$
$r_{P\Delta E.Cu}$	-0.086	$+0.176$	$+0.039$	-0.010	$+0.082$
$r_{Cu\Delta E.S}$	-0.027	-0.161	-0.180	-0.326	$+0.010$
$r_{Cu\Delta E.P}$	-0.041	-0.063	-0.101	-0.284	$+0.045$
Second-Order Partial Correlation Coefficients.					
$r_{S\Delta E.PCu}$	-0.312	-0.399	-0.335	-0.399	-0.341
$r_{P\Delta E.SCu}$	$+0.202$	$+0.405$	$+0.268$	$+0.292$	$+0.318$
$r_{Cu\Delta E.SP}$	$+0.080$	$+0.146$	$+0.026$	-0.072	$+0.205$
Third-Order Partial Correlation Coefficients.					
$r_{T\Delta E.SPCu}$	-0.045	-0.249	-0.398	-0.204	-0.321
$r_{TS.PCu\Delta E}$	$+0.168$	$+0.206$	-0.223	-0.152	$+0.022$
$r_{TP.SCu\Delta E}$	-0.311	-0.063	-0.088	-0.061	-0.032
$r_{TCu.SP\Delta E}$	-0.037	$+0.171$	$+0.058$	$+0.177$	-0.017

The coefficients not involving T may be considered first.

(*a*) $r_{S\Delta E}$, $r_{S\Delta E.P}$, $r_{S\Delta E.Cu}$, $r_{S\Delta E.CuP}$.—As in Part I., several significant negative values of $r_{S\Delta E.P}$ and $r_{S\Delta E.Cu}$ are found, and the final weighted-mean value of $r_{S\Delta E.PCu}$ as estimated by Fisher's "z" method, [2] for the five present and seven previous determinations, is -0.364, which is significant. Thus, the previous conclusion, that increase of cathodic increment is associated with decrease of sulphur content when phosphorus content is kept constant, is confirmed.

(b) $r_{P\Delta E}$, $r_{P\Delta E . S}$, $r_{P\Delta E . Cu}$, $r_{P\Delta E . SCu}$.—Similarly, some of the values of $r_{P\Delta E . S}$ and $r_{P\Delta E . SCu}$ are significant, and the final weighted-mean value of $r_{P\Delta E . SCu}$, $+ 0.351$, is significant. Thus, increase of cathodic increment is associated with increase of phosphorus content when sulphur content is kept constant.

(c) $r_{Cu\Delta E}$, $r_{Cu\Delta E . S}$, $r_{Cu\Delta E . P}$, $r_{Cu\Delta E . SP}$.—Insignificant values are always found, as before.

The interesting coefficients involving T are the following :

(d) $r_{T\Delta E}$, $r_{T\Delta E . SPCu}$.—Significant negative values of $r_{T\Delta E}$ are found for cherries, gooseberries and prunes in plain cans, and for $r_{T\Delta E . SPCu}$ for gooseberries only. Thus, for gooseberries, increase of T is associated with decrease of cathodic increment, whether or not sulphur, phosphorus and copper contents are kept constant; while for cherries and prunes, the significant association is only found when sulphur, phosphorus and copper contents are allowed to vary naturally, this being no doubt due in part to the combined influence of sulphur and phosphorus on the cathodic increment (see (a) and (b) above).

(e) $r_{TS . PCu\Delta E}$, $r_{TP . SCu\Delta E}$, $r_{TCu . SP\Delta E}$.—All the values are insignificant, the elimination of the ΔE factor giving no increase in the correlations.

These results may be summarised in a practical way. In steels of the present type, those having higher phosphorus content (sulphur being kept constant) possess cathodic points of greater efficiency for the reaction

$$2H^+ + 2\epsilon \rightarrow H_2$$
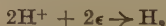
when they corrode in citric acid ; and those having higher sulphur content (phosphorus being kept constant) possess less efficient cathodes. Copper content is immaterial in this respect. Also, good cathodic efficiency of the steel base leads to more rapid production of hydrogen-swells in plain-can packs of white cherries, gooseberries and prunes—in the case of gooseberries, even when sulphur, phosphorus and copper contents are kept constant—but is immaterial in lacquered-can packs of Czar plums and in plain-can packs of Pershore plums.

IV.—General Discussion.

(1) The Metallurgical Correlations and the Cathodic Increment.

It will be convenient to summarise in tabular form the weighted-mean values of the partial correlation coefficients of sulphur, phosphorus and copper contents and the cathodic increment, as determined for all twelve packs. These are obtained, from the individual values to be found in Tables XII. and XIII. of Part I. and in Tables XXVII. and XXVIII. of this paper, by Fisher's " z " method.[2] Table XXIX. gives the results.

TABLE XXIX.—*Mean Metallurgical Correlations.*

Coefficient.			Mean Value.	Coefficient.			Mean Value.
$r_{SP.Cu}$	.	.	+0·771	$r_{S\Delta E.PCu}$	.	.	−0·364
$r_{SCu.P}$	.	.	+0·419	$r_{S\Delta E.SCu}$	.	.	+0·351
$r_{PCu.S}$	.	.	−0·573	$r_{Cu\Delta E.SP}$	.	.	+0·106

The first five coefficients of this Table are significant. Possible explanations of these metallurgical correlations have been given in Part I., Section IV. (1), and a further cause of the marked negative correlation between phosphorus and copper has been suggested in a series of valuable conversations with South Wales metallurgists : If for any reason the phosphorus content of a finished steel base is to be fairly high, it is considered good steel-making practice to keep the copper content as low as possible by using low-copper scrap; if, however, the phosphorus content is to be low, opportunity is taken to utilise higher-copper scrap. We may observe that generally (though not necessarily) high-phosphorus/low-copper steel is produced by the acid open-hearth, whereas low-phosphorus/high-copper steel is produced by the basic process. We have shown that low-phosphorus/high-copper steel base is (for one reason or another) advantageous in the tinplate used for at least ten kinds of fruit packs in lacquered and plain cans, and while it would be inaccurate to say that basic steel is preferable for this purpose, it is true that the desirable low-phosphorus/high-copper material is much more often found among the products of the basic than of the acid open-hearths. Since steel-makers usually work to at least approximate specifications, there appear to be no technical reasons (in normal times) why tinplates for fruit-packing should not be made from steel base of desirable composition, in this case low-phosphorus/high-copper. This kind of grading is already in partial use in the United States.

The present results confirm the small correlations of the cathodic increment of the steel base with its sulphur and phosphorus contents, and the lack of any relationship with copper content. The individual values of $r_{S\Delta E.PCu}$ and $r_{P\Delta E.SCu}$ for the twelve packs of Parts I. and II. are plotted against each other as a scatter diagram in Fig. 11. The high correlation between these coefficients shows clearly that the influence causing the wide scatter of their values as determined is common to both determinations. This common influence is clearly the relatively large experimental error in ΔE,* mentioned in Part I., Section III. (7); and the high correlation between the determined values of the two coefficients, together with their significant mean values, shows that if it were possible to obtain more accurate values of ΔE, the determined

* The error may, indeed, be regarded as an uneliminated variate.

values of each coefficient would be higher, and their mean values higher and of higher significance. This promotes confidence in the results.

A further factor influencing the cathodic increment is very probably the cementite content and distribution as discussed in Part I., Section IV. (2) and in a previous paper.[3] This requires investigation.
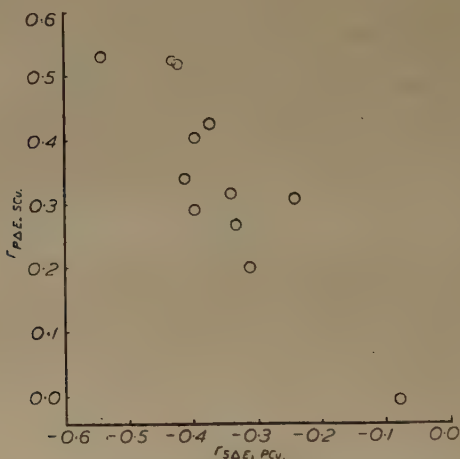
FIG. 11.—Correlation of $r_{S\Delta E . PCu}$ with $r_{P\Delta E . SCu}$.

(2) Comparison of Plain- and Lacquered-Can Packs.

Three fruits, sweet white cherries, gooseberries and yellow Pershore plums, have been studied in packs of plain and lacquered cans, with results given here and in Part I. The plain packs all gave much slower formation of hydrogen swells, a well-known effect due to the inhibiting influence of dissolved tin on steel corrosion, together with the relatively slow corrosion of the tin itself.

It is particularly to be noted that, while the lacquered-can pack of gooseberries showed a significant positive correlation between time of formation of hydrogen-swell and copper content ($r_{TCu . SP} = + 0.361$, Part I., Table XII.), and the lacquered-can pack of Pershore plums a significant negative correlation between time of swell and phosphorus content ($r_{TP . SCu} = - 0.371$, Part I., Table XII.), these correlations are not found in the plain packs of these fruits; nor do the other two plain packs give either correlation. Indeed, the only significant correlations between time of swell and composition variates in plain-can packs are $r_{TP} = - 0.398$ for gooseberries and $r_{TS . P} = + 0.407$ for cherries, which are undoubtedly due to the combined influence of several variates,

none of which is sufficiently important (except ΔE) to have a significant influence by itself. But the significant negative correlation of time of swell with cathodic increment found for cherries and gooseberries in lacquered-can packs ($r_{T\Delta E} = -0.556$ and -0.475 respectively, Part I., Table XIII.) also appears in the plain packs of these fruits ($r_{T\Delta E} = -0.355$ and -0.362 respectively), and in the plain pack of prunes ($r_{T\Delta E} = -0.349$). Evidently the influences of copper and phosphorus contents on the steel-base corrosion in the can (where they occur) are largely eliminated when the tin coating also is exposed to the corrosive fruit juice, but the influence of the cathodic efficiency of the steel base (where it occurs) is not eliminated by exposed tin. These two points are readily explained : The tin coating acts as an inhibitor of the anodic reaction

$$Fe \rightarrow Fe^{++} + 2\epsilon$$
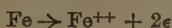
on the steel, for the main anodic attack is diverted on to the less noble tin and the remaining anodic action on the steel is strongly inhibited by dissolved tin ions ;[4] and since the influence of copper content (and probably most of that of phosphorus) on the steel-base corrosion is exerted on the anodic part of the reaction,[3] their influences become unimportant when the steel anodic reaction is relatively unimportant, i.e., in plain cans. But on the other hand, the cathodic points on the exposed steel are important whether or not the main anodes are on the steel or on the tin coating, because the cathodic points on the tin are extremely inefficient ; * thus the steel cathodic increment, when important in lacquered-can packs, is also so in plain-can packs of the same fruit.

The generalisation may therefore be made, that steel-base composition is not very important in plain-can packs of fruit except in so far as it affects the cathodic increment owing to the distinctly significant correlations of sulphur and phosphorus contents with cathodic increment, or to other unknown influences of composition on cathodic increment. It is, however, desirable that the cathodic increment should be as negative as possible for plain-can packs of gooseberries, cherries and prunes, and very possibly also for other plain-can packs ; and it may be pointed out in passing that the experimental determination of the approximate cathodic increment, by means of the corrosion and potential measurements described in Sections II. (6b) and III. (6) of Part I., is no more difficult than chemical analysis.

(3) *Comparison of Fruits.*

It may be pointed out that the only fruits showing significant correlation between the time of formation of hydrogen-swell and

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* In electrochemical terminology, because tin has a high hydrogen overpotential.

the cathodic increment of the steel base are white cherries, gooseberries and prunes (the former two in both lacquered- and plaincan packs). These fruits contain far less natural anthocyanin colouring matter than black currants, loganberries, Czar plums, raspberries and strawberries, where the cathodic increment correlation does not occur. It thus seems very possible that the differences in cathodic activity between different steel bases are smoothed out by the presence of anthocyanins. Another notable difference between fruits is that only cherries among those investigated show no correlation of time of formation of hydrogen-swell with either copper- or phosphorus-content of the steel base, in lacquered-can packs. The comparatively high pH, 4·40, of the cherries may be the cause of this; the influences of copper- and phosphorus-contents on steel corrosion, though marked in acids, are small in neutral solutions.

Fruit juices undoubtedly contain in general corrosion accelerators such as anthocyanins and corrosion inhibitors such as proteins, pectins and gums, and these probably act on both cathodic and anodic corrosion reactions. The complex situation thereby produced could be considerably clarified by the electrochemical methods for accelerator and inhibitor classification discussed elsewhere.[5] Experiments to determine the corrosion rates and corrosion potentials, in aerated and de-aerated fruit juices, of various steels and of tin would have great academic interest, and would throw light on the differences between different fruits such as those referred to at the beginning of this sub-section. It is hoped to initiate this work when conditions permit.

(4) *The Testing of Tinplate for Fruit Packs.*

The unexpected poorness of the correlation between time of formation of hydrogen-swell and the corrosion test of the steel base in the same fruit juice prompts several observations on the design of reliable testing methods for tinplate to be used in fruit packs. As has been shown (Section III. (4)), corrosion tests of steel base in fruit juice open to the air fail because we desire a knowledge of the rate of hydrogen evolution and not of oxygen absorption; while very rapid tests in hot mineral acid are unexpectedly promising, since here hydrogen evolution greatly predominates. If, however, a low-temperature and less rapid test is thought desirable, it is clear that nearly anaerobic conditions are still a first requisite; and since a closed system is essential for this (at room temperature), it will introduce no further experimental complication if we measure *gas evolved* rather than *steel dissolved* as the criterion of corrosion, in order to approach nearer to the practical case of the hydrogen-swell. For the same reason, the time taken to evolve a standard volume of gas, rather than the volume evolved in a standard time, will be our best measure; and it will be advantageous if only *one side* of the metal is attacked,

so that hydrogen-diffusion through the metal occurs as in the practical case. These conditions have already been proposed by Vaurio, Clark and Lueck in their test of tinplate for plain-can packs: [6] A can-end is kept with one side in contact with dilute hydrochloric acid until a standard volume of gas is evolved, and the result has been shown to correlate well with canning tests. For a test of tinplate for *lacquered*-can packs, however, it is clearly essential to have the tin coating absent, since the attack in a lacquered can is almost entirely on the steel and little tin comes into the picture; and the test of Vaurio, Clark and Lueck, to be rational, would here have to be modified by working with tinplate from which the coating of tin and tin-iron compound had been removed.

Other less obvious desiderata may be noted. For example, since it is usual to find perforation of a can taking place not long after (sometimes even before) hydrogen-swell formation, the corrosion testing of the tinplate or its steel base should take account of the interior of the steel as well as the surface layers, which may be quite unrepresentative. This could probably be best achieved in a test on de-tinned steel base carried on until some two-thirds of the total thickness had been removed, excess of acid of course being present.

The use of fruit juice, organic acid or mineral acid as corrosive will be determined by the rapidity of test desired; there appears, however, to be little improvement to be had from the use of organic rather than mineral acid and, until more is known about the reproducibility of fruit juice from one batch to another, little to be said for the necessarily slow fruit-juice test. Similarly, although a high temperature appears at first sight unjustifiable (owing to differences in temperature coefficients among the steels tested), the present tests in hot acid lead us to think that this procedure has less to its discredit than has been thought.

Two types of test, therefore, appear to offer promise and to deserve thorough experimental investigation. For a rough but rapid test, pickling in boiling acid may be as good a method as any. For more precise work, a technique in which one side of a specimen of de-tinned tinplate is exposed to warm (50° C.) mineral acid until about two-thirds of its thickness has been corroded should give interesting information; as in the test of Vaurio, Clark and Lueck, the time taken to evolve a standard amount of hydrogen on the corroding side of the metal would be an appropriate measure of corrodibility. For a specimen of area 10 sq. cm., the total amount of hydrogen produced during the dissolution of 0·02 cm. of its thickness in acid is about 550 ml., of which part will be evolved on the corroding side of the steel and part diffused through it; an evolution of, say, 250 ml. might be taken as the standard amount, and the time for this measured. It should be emphasised that such a test could be adopted for general use only

after extensive and successful checking of its results with those of canning trials.

(5) *Recommended Tinplate Steel Base.*

We may conclude with a tabular summary, Table XXX., setting forth the main conclusions of Parts I. and II. of this research with regard to the most suitable tinplate steel base for the various fruit packs investigated. It must be emphasised that these recommendations refer *only* to pack-rolled steel base as normally manufactured in this country prior to the present war. Where a recommendation is bracketed, it is of subsidiary importance.

TABLE XXX.—*Recommended Tinplate Steel Base for Various Packs.*

HS : High sulphur (phosphorus normal).
$L\Delta E$: Cathodic increment as negative as possible.
LP/HCu : Low phosphorus/high copper.

Fruit.	Lacquered Cans.	Plain Cans.
Black currants . . .	LP/HCu	...
Sweet white cherries . .	$L\Delta E$	$L\Delta E$: (HS)
Gooseberries	LP/HCu : $L\Delta E$	$L\Delta E$: (LP/HCu)
Loganberries	LP/HCu	...
Czar plums	LP/HCu	...
Pershore plums . . .	LP/HCu	Immaterial
Prunes	...	$L\Delta E$
Raspberries	LP/HCu	...
Strawberries	LP/HCu	...

V.—SUMMARISED CONCLUSIONS.

The general conclusions of Part I. are confirmed, and the particular conclusions are supplemented as follows :

(1) For packs of Czar plums in double-lacquered cans and for packs of gooseberries in plain cans, the use of low-phosphorus/high-copper steel base, shown in Part I. to be desirable for six other packs, is to be preferred, though the resulting improvement on packs made from unselected material is likely to be somewhat less marked than in the six previously reported cases. For packs of sweet white cherries, Pershore plums and prunes in plain cans, the phosphorus and copper contents of the steel base are immaterial, except in so far as they influence the cathodic increment discussed below. For such packs of cherries, there may be some advantage in a higher-sulphur steel base, but sulphur content is immaterial in all the other cases here reported.

(2) For the packs of sweet white cherries, gooseberries and prunes here studied, the rate of formation of hydrogen-swells was significantly smaller for cans made from steel bases showing lower cathodic increments; thus it is probable that such steel base is in general desirable for such packs.

(3) For the packs of raspberries, strawberries (Part I.) and Czar plums (Part II.) in double-lacquered cans, the corrosion rate of the can steel base in fruit juice gave a poorer correlation with the time of formation of hydrogen-swell than did the corrosion rate in citric acid, while the corrosion rate in boiling dilute hydrochloric acid (11% HCl by weight) gave the best correlation of all. Reasons for these results are advanced, and suggestions for rational corrosion tests of tinplate based on them are made.

(4) Differences between lacquered- and plain-can packs are discussed. It is suggested that steel-base composition is important for plain-can packs mainly in so far as it influences the cathodic increment.

(5) Differences between fruits due to the unknown influences of their complex constituents are discussed, and suggestions for further clarification of this matter are made.

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THE LADLE COOLING OF LIQUID STEEL.[1]

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*Paper No. 1/1941 of the Steel Castings Research Committee
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SUMMARY.

It is now possible to control and measure with accuracy the temperature of liquid steel in the melting furnace, and thus it has become important to know what fall in temperature is to be expected between tapping and casting. The present paper explains how this may be calculated. A simple experiment with a model shows how the metal in the ladle cools by a relatively thin layer of metal passing down the vertical walls of the refractory lining and forming a reservoir of cool metal at the bottom of the ladle. The amount of heat extracted by the ladle refractories is calculated, and particular attention is drawn to the effect of preheating the ladle. It is deduced that, to obtain efficient preheating, the preheating period must bear a definite relation to the time taken to tap and cast. The results of the investigation are presented in the form of a Table which gives the drop in temperature for different sizes of ladle and different times of casting and tapping. It is shown that the effect of varying the tapping temperature and the temperature to which the ladle is preheated can be allowed for by multiplying the figures in the Table by a simple factor. A second Table gives corrections which may be applied for different methods of casting and for the time that the metal is held in the ladle between tapping and casting. The theory goes far to explain certain unexpected results in observed casting temperatures.

The conditions for obtaining a uniform casting temperature are outlined. An Appendix summarises the mathematical approach to the problem.

THE development of the Schofield-Grace method of liquid-steel temperature measurement has made possible a very accurate control of temperature in the melting furnace. From the foundry angle it is equally important to know the temperature at which the metal is cast and to be able to control the tapping temperature so that a predetermined casting temperature is obtained. Between tapping and casting there is a fall in temperature of between 50° and 150° C. according to the ladle conditions. It is the purpose of this paper to obtain a clearer understanding of the mechanism of cooling in the ladle and to determine how the magnitude of the cooling is affected by the dimensions of the ladle, the physical properties of the refractory lining and the preheating treatment

[1] Received August 29, 1941.

which it has been given. It should then be possible to predict
with confidence the fall in temperature between tapping and casting
under given conditions.

(1) *The Mechanism of Convective Cooling.*

It is not possible to observe directly the movement of the
liquid steel in a ladle, so a simple experiment was carried out with
a model, using medicinal paraffin, which has a viscosity of the same
order as that of liquid steel. The paraffin was heated to about
60° C. in a 500-ml. Pyrex beaker, which was then cooled by immer-
sion in a larger beaker of cold water. The motion of the liquid
was shown up by finely powdered chromic oxide held in suspension.
A narrow beam of light formed by a thin vertical slit was pro-
jected through the liquid and the motion of the particles observed
at right angles to this beam. In this way the movement of a
vertical section of the liquid was isolated and made visible. The
rate of flow of the liquid and the exact shape of the lines of flow
depend on a number of factors such as the viscosity, density,
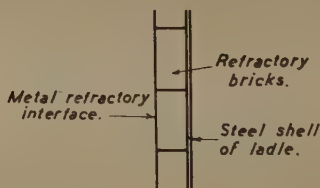
Fig. 1.—Section of Ladle Wall.

thermal conductivity and coefficient of thermal expansion, and it
was not thought necessary to attempt to reproduce the exact con-
ditions of the ladle in this respect. The motion should be very
similar, although not quantitatively comparable.

It was found that a thin layer of liquid about 3 mm. thick
flowed down the vertical sides of the beaker from top to bottom.
This liquid was drawn from the surface layer of the paraffin about
1 cm. thick. At first it was noticed that the layer immediately
next to the falling layer was rising more rapidly than the rest of
the liquid, but this effect was later less noticeable. After about 3
min. there was a cool layer at the bottom of the beaker extending
about half-way up, while the top was still hot. Convection had
slowed up considerably and was very slow in the lower cool layer.
When a tube was put into the beaker and liquid syphoned off
slowly from the bottom a considerable swirling action occurred,
liquid being drawn off from the bottom third of the beaker.

(2) *Calculation of Heat Extracted by the Refractory Lining.*

Consider the simplified system, Fig. 1, where the metal-refractory interface is losing heat through the brickwork to the shell of the ladle, from which again it is lost by radiation and convection. Certain further simplifying assumptions will be made, as outlined below, which will not substantially affect the accuracy of the calculations.

The notation adopted is as follows :

θ = temperature of refractory at depth x and time t (° C.).
θ_T = temperature of metal tapped (° C.).
θ_I = temperature of refractory-metal interface (° C.).
θ_σ = mean temperature of metal cast (° C.).
θ_1 = inner surface temperature of bricks after preheating (° C.).
W = weight of metal cast (tons).
R = internal radius of ladle (cm.).
T = time from commencing tapping to finishing casting (sec.).
τ = time from finishing tapping to commencing casting (sec.).
$n^2 = \tau/T$.
t_0 = time of preheating (sec.).
φ = density of bricks (taken as 2·0 g. per c.c.).
σ = specific heat of bricks (taken as 0·25 c.g.s. units).
κ = thermal conductivity of bricks (taken as $6·4 . 10^{-3}$ c.g.s. units).
a^2 = thermal diffusivity of bricks (taken as 0·0128 c.g.s. units).
ρ' = density of liquid steel (taken as 7·5 g. per c.c.).
σ' = specific heat of liquid steel (taken as 0·11 c.g.s. units).
κ' = thermal conductivity of liquid steel (taken as $12 . 10^{-2}$ c.g.s. units).

In the following mathematical treatment the refractory lining is considered as a " semi-infinite " slab, the plane surface of which is suddenly raised to a certain temperature and maintained at that temperature so long as it is in contact with the metal. In deciding what value should be chosen for this surface temperature it has been assumed that the system behaves as if it consisted of two dissimilar semi-infinite solid bodies originally at different uniform temperatures, the plane surfaces of which are suddenly brought into contact. Calculation shows that in a semi-infinite slab heated in this way the temperature at time t at a depth $2·3\sqrt{a^2t}$ from the hot surface is one-tenth of the surface temperature, and that less than 10% of the heat absorbed at the hot surface has penetrated beyond this point. This depth is found to be 5 in. for a 25-ton ladle, when the time from tapping to finished casting is 40 min. In practice such a ladle is lined with at least $4\frac{1}{2}$-in. bricks, so that the assumption of a semi-infinite solid will introduce very little error into the calculations. The thickness of brick used in ladles of other capacities is equally satisfactory from this point of view.

The calculations made below refer to a ladle of which the height is equal to the diameter. In a ladle of which the depth is twice the diameter the drop in temperature will be about 10% more, and in one in which the depth is half the diameter about 5% less. It is assumed that the layer of slag on the surface of the metal

prevents any appreciable loss of heat from the metal at the exposed surface.

The temperature θ_I of the refractory-metal interface is given by the formula :

$$\frac{\theta_T - \theta_I}{\theta_I} = \sqrt{\frac{\rho\sigma\kappa}{\rho'\sigma'\kappa'}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This is strictly true only for two solids in contact, and the actual temperature may be rather higher at some points in the ladle, owing to the motion of the liquid, and rather lower at the end of the casting period, but the equation provides a useful estimate of the surface temperature. The value of the thermal conductivity of liquid steel is not known with high accuracy and this is a major source of error in estimating θ_I.

The rate of extraction of heat by the refractory lining is given by :

$$\theta_I \sqrt{\frac{\rho\sigma\kappa}{\pi t}} \text{ per unit area,} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

when the ladle is not preheated. Integrating this function, it is found that for a full ladle the total heat extracted up to time t is given by :

$$Q = 10\theta_I \sqrt{\rho\sigma\kappa\pi} \cdot R^2 t^{\frac{1}{2}}. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In calculating the heat extracted during tapping and casting, allowance must be made for the varying area of surface in contact with the steel. If the casting is allowed to take place freely under gravity the casting rate will be proportional to the square-root of the depth of metal in the ladle. The total drop in temperature in the ladle is then found to be :

$$\theta_T - \theta_C = \frac{1}{15}\theta_I \sqrt{\frac{\rho\sigma\kappa}{\pi}} \cdot \frac{T^{\frac{1}{2}}}{27\cdot8 \cdot W^{\frac{1}{2}} \cdot \rho'\sigma'} \cdot \left\{47 + \frac{16n^2(4 + 3n)}{(1 + n)^2}\right\} \quad . \quad (4)$$

If the metal is cast through a series of similar tundishes, the rate of casting is regulated by hand to be almost uniform, and the drop in temperature is then given by :

$$\theta_T - \theta_C = \frac{1}{3}\theta_I \sqrt{\frac{\rho\sigma\kappa}{\pi}} \cdot \frac{T^{\frac{1}{2}}}{27\cdot8 \cdot W^{\frac{1}{2}} \cdot \rho'\sigma'} \cdot \left\{11 + \frac{8n^2}{(1 + n)}\right\} \quad . \quad (5)$$

(3) *Preheating the Ladle.*

It is not possible to calculate the exact effect of preheating the ladle, but it can be estimated with sufficient accuracy for practical purposes. What is observed is the surface temperature θ_I of the refractories. The quantity p is defined by saying that the ladle extracts the same amount of heat as one with the refractories heated uniformly to a temperature $p\theta_i$. An upper limit to the value of p is obtained by assuming that the inner surface had been

maintained at θ_l for the whole preheating time t_0. This leads to the expression :

$$p < 1 - \sqrt{1 + \frac{2t_0}{T + \tau}} + \sqrt{\frac{2t_0}{T + \tau}} \quad . \quad . \quad . \quad (6)$$

A lower limit is obtained by considering a constant rate of heat input at the metal-refractory interface, and this gives an approximate formula :

$$p > 1 - \sqrt{1 + \frac{1 \cdot 28t_0}{T + \tau}} + \sqrt{\frac{1 \cdot 28t_0}{T + \tau}} \quad . \quad . \quad . \quad (7)$$

It will be seen that the value of p depends on the ratio of the preheating time to the sum of the total time T and the time held in the ladle τ. The following figures show how p varies with this ratio :

$\frac{t_0}{T + \tau}$	$\frac{1}{2}$.	2.	$4\frac{1}{4}$.	8.	$12\frac{1}{2}$.
p	0·55	0·73	0·82	0·86	0·89

When the ladle is allowed to cool before casting begins, the effective surface temperature θ_l is rather lower than the maximum attained, but considerably higher than the temperature to which it cools. Unfortunately it seems impossible to give any quantitative data on this subject, but under normal circumstances this is not of great practical importance.

Formulæ for the loss of temperature in the ladle can now be given. Taking $\theta_I = 0 \cdot 9\theta_T$ (see equation (1)), we have, in the case of free casting under gravity :

$$\theta_T - \theta_C = b \cdot \frac{T^{\frac{1}{2}}}{W^{\frac{1}{3}}} \cdot (0 \cdot 9\theta_T - p\theta_l) \left(47 + \frac{16n^2(4 + 3n)}{(1 + n)^2} \right) \quad . \quad . \quad (8)$$

and for casting at a uniform rate :

$$\theta_T - \theta_0 = b \frac{T^{\frac{1}{2}}}{W^{\frac{1}{3}}} \cdot (0 \cdot 9\theta_T - p\theta_l) \left(55 + \frac{40n^2}{(1 + n)} \right) \quad . \quad . \quad (9)$$

b is a constant taken as $9 \cdot 28 \cdot 10^{-5}$.

(4) *Practical Figures.*

Table I. shows the difference between the tapping stream temperature and the mean casting temperature for different weights of metal and times of casting. The figures are correct for a difference of 1000° C. between the tapping temperature (θ_T) and the surface temperature (θ_l) of the ladle refractories before tapping. For other values of $\theta_T - \theta_l$ the figures in the Table must be multiplied by $(\theta_T - \theta_l)/1000$. A small correction is necessary to allow for the time τ for which the ladle is held full of metal between tapping and casting. The correction is shown in Table II. in terms of the fraction τ/T, where T is the total time from commencing tapping

TABLE I.—*Difference between Tapping Temperature and Mean Casting Temperature (° C.).*

The Table is correct for a difference of 1000° C. between ladle temperature and tapping temperature.

Weight of Metal in Ladle.	Time (*T*) from Commencing Tapping to Finishing Casting. Min.																						
	1.	1½.	2.	3.	4.	5.	7.	10.	12.	15.	18.	20.	25.	30.	35.	40.	45.	50.	60.	70.	80.	90.	120.
1 cwt.	106	122	150	183	212	237	280																
2 "	84	102	118	145	167	187	221	267															
5 "	62	75	87	107	123	137	163	195	213	238													
10 "	49	60	69	85	98	109	129	155	170	190	208	219	245	268									
1 ton		48	55	67	78	87	103	123	135	150	165	173	194	212									
2 tons			43	53	62	69	81	97	107	119	131	137	154	169	182	195							
3 "				47	54	60	71	85	93	104	114	120	134	147	159	170	180	190	208				
5 "				39	45	51	60	72	79	88	96	102	113	124	134	143	152	160	176				
7 "				35	41	45	54	64	70	79	86	91	102	111	120	128	136	143	157				
10 "				31	36	40	48	57	62	70	77	81	90	99	107	114	121	127	140				
15 "				27	31	35	42	50	55	61	67	70	79	86	93	100	106	112	122				
20 "				25	29	32	38	48	50	55	61	64	71	78	85	91	96	101	111				
25 "								42	46	51	55	59	66	73	79	84	89	94	103				
30 "								36	43	48	48	56	62	68	74	79	84	88	97				
40 "									39	44	45	51	57	62	67	72	76	80	88	95	101	107	124
50 "										41	39	47	53	58	62	67	71	75	82	88	95	100	115
75 "										36		41	46	50	54	58	62	65	71	77	82	87	101
100 "												38	42	46	50	53	56	59	65	70	75	80	92

to finishing casting. The correction is different for a uniform casting rate (as is obtained by casting through tundishes) and for free flow under gravity. It is assumed that $p = 0.9$, *i.e.*, the ladle has been preheated for at least 15 times the casting time.

TABLE II.—*Correction to be Added to Figures in Table I. to Allow for the Time τ for which the Ladle is Held full of Metal between Tapping and Casting.*

τ/T :	0.	0·1.	0·2.	0·3.	0·4.	0·5.	0·6.	0·7.	0·8.	0·9.	1·0.
Correction for uniform casting rate	− 8%	− 3%	+1%	+5%	+8%	+12%	+15%	+17%	+20%	+23%	+25%
Correction for free flow	−22%	−14%	−8%	−3%	+2%	+ 6%	+10%	+14%	+18%	+22%	+25%

A specific example will make the use of the Table clear. Consider a 25-ton ladle initially preheated to a surface temperature of 400° C. The temperature of the metal as it is tapped out of the furnace is 1620° C. The time from commencing tapping to finishing casting is 40 min., and before casting the metal is held in the ladle for 5 min. Table I. shows that for a 25-ton ladle and a time of 40 min. the drop in temperature under standard conditions is 84° C. Now the difference between tapping temperature and ladle temperature is 1220° C., so the figure of 84° C. must be multiplied by 1220/1000, giving a figure of 102° C. The correction for the time held in the ladle, which is one-eighth of the total time of the operation, is now applied. Table II. shows that the correction for uniform casting rate is − 2% (*i.e.*, − 2° C.) and for free flow − 12% (*i.e.*, − 12° C.). Thus the temperature drop should be 100° C. and 90° C., respectively, under the two conditions of casting.

Table III. gives a few examples worked out for different sizes of ladle. The figures have been compared with the results of optical-pyrometer readings taken during routine observation. The comparison shows a very reasonable agreement when the usual emissivity corrections are taken into account, but the observational conditions are such as to make the results of only limited value. It is very desirable to have a direct comparison of readings taken with the quick-immersion thermocouple in launder and casting streams. This is possible in certain cases where tundishes are used, and it is hoped that such observations will be made in the near future. To obtain values in good agreement with observed temperatures thermal constants have been used which are a little higher than those usually accepted for the aluminous firebricks used to line ladles. However, the calculations take no account of the variation of thermal constants with temperature and some arbitrary choice of constants is unavoidable. The consistent agreement with

observation over a very wide range of conditions is considered sufficient confirmation of the theory at present.

TABLE III.—*Calculated Values of Loss of Temperature in Ladle under Various Conditions.*

Weight of Metal Cast. Tons.	Time from Commencing Tapping to Finishing Casting. Min.	Time Held in Ladle before Casting. Min.	Initial Temp. of Metal. ° C.	Preheating Temp. of Ladle. ° C.	Correction for Loss of Temperature, ° C., for—	
					Uniform Casting Rate.	Free Flow from Ladle.
40	53	10	1620	300	110	100
	40	5	1620	300	90	80
25	33	7	1620	400	95	85
	40	5	1620	400	100	90
10	13	3	1620	600	65	60
	13	3	1620	300	85	80
$4\frac{1}{4}$	33	4	1600	700	125	110
$2\frac{1}{2}$	$12\frac{1}{2}$	3	1480	850	65	60
	$12\frac{1}{2}$	3	1480	650	85	80
$\frac{1}{4}$	3	$1\frac{1}{2}$	1600	800	95	90
	$5\frac{1}{2}$	4	1600	800	135	130

If other types of brick are used to line the ladle, all the figures quoted must be multiplied by a constant factor, which is given by the ratio $\sqrt{(\rho_2\sigma_2\kappa_2)/(\rho_1\sigma_1\kappa_1)}$, where the suffixes 1 and 2 refer to the two types of brick. The best practical method is to compare actual and theoretical values in one or two typical cases and so to deduce the necessary factor.

The picture of the mechanism of cooling outlined gives an explanation of the very uniform casting temperature obtained with a series of ingots cast through tundishes from a 25-ton ladle. It has been found that when the temperature of the metal is measured in each tundish with a quick-immersion pyrometer, the temperature is constant during the whole cast within approximately 5° C. This is at first sight surprising, because the temperature at the top of the ladle is known to have fallen very little at the time when casting begins. However, calculation shows that more than half the cooling effect of the ladle is complete before casting is commenced. It is clear that a cool layer of liquid is formed in the bottom half of the ladle, and this acts as a reservoir from which metal is drawn off during casting. This reservoir is replenished by further cooled metal as casting proceeds. Although it cannot be calculated exactly, it appears that the mean temperature of the cool layer will be about 90° C. below the tapping temperature.

Another effect in foundry practice which is explained is the large difference in temperature between the first and last casting when the metal is " lip-poured " from a ladle. When casting commences the top layer of the metal is only perhaps 40° C. below

the tapping temperature, while the metal at the bottom of the ladle is much cooler. The first castings are made from hot metal poured from the top of the ladle and the last castings from metal which has been in contact with the refractory lining ever since tapping. The difference in temperature between the first and last castings may on occasions be nearly 100° C. When it is desired to obtain a uniform casting temperature it is essential to have a ladle with a stopper, so that the cold layer of metal at the bottom is withdrawn from the ladle first, and the hot metal at the top is cooled by contact with the sides of the ladle before it is cast. It is also advisable to allow the metal to stand in the ladle long enough to allow the formation of a reservoir of cold metal at the bottom of the ladle.

(5) *Mathematical Appendix.*

The formula $\theta_I \sqrt{(\rho\sigma\kappa)/(\pi t)}$ for the rate of extraction of heat per unit area of surface may be obtained by differentiating the equation : [1]

$$\theta = \theta_I \left\{ 1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{a^2 t}}} e^{-\xi^2} d\xi \right\},$$

which gives the temperature distribution after time t in a semi-infinite solid of which the surface $x = 0$ is raised to a temperature θ_I at zero time.

Consider a cylindrical ladle of which the height is equal to its diameter $(2R)$. Let the ladle be completely full for time τ and be in the process of filling and emptying for the remaining time $(T - \tau)$. The curve $ABCD$ in Fig. 2 shows the depth of metal in the ladle after time t. PQ represents the time for which a certain point on the refractory surface is in contact with the metal. If, now, a curve $AEFD$ (Fig. 3) be drawn such that $EF = BC$, it will be seen that $RS = PQ$. Thus, the total heat extracted is the same as if the ladle had been filled instantaneously at time $t = 0$, held for time τ, and then emptied at a uniform rate during the period τ to T. It will be seen that the area of refractory surface in contact with the metal from $t = 0$ to $t = \tau$ is $5\pi R^2$, and from $t = \tau$ to $t = T$ the area is $\pi R^2\{1 + 4(T - t)/(T - \tau)\}$. Thus the total heat extracted is :

$$\theta_I R^2 \sqrt{\pi\rho\sigma\kappa} \left\{ 5\int_0^\tau t^{-\frac{1}{2}}dt + \int_\tau^T \left\{ 1 + 4\frac{(T - t)}{(T - \tau)} \right\} t^{-\frac{1}{2}}dt \right\} \quad . \quad . \quad (11)$$

When the metal is allowed to flow freely from the ladle under gravity it is again assumed that the casting and tapping periods

[1] H. S. Carslaw : " Introduction to the Mathematical Theory of the Conduction of Heat in Solids." London, 1921 : Macmillan & Co., Ltd.

may be considered together. This is strictly true in either case only if the metal is tapped into the ladle at a rate which increases in the same way as the casting rate decreases. The casting time is, however, normally so much longer than the time taken to fill the ladle that the error introduced is of no practical importance.
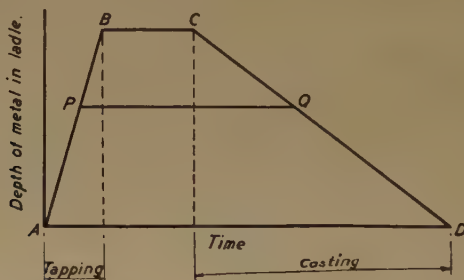
Fig. 2.
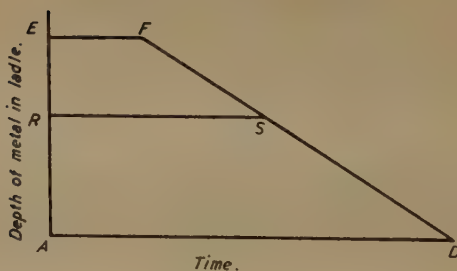
Fig. 3.

When the metal is allowed to flow freely from the ladle under gravity the depth of metal in the ladle (h) falls according to the well-known equation

$$\frac{dh}{dt} = -Ah^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Integrating this equation gives :

$$h = 2R\frac{(T-t)^2}{(T-\tau)^2} . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Thus the formula for the total heat extracted is obtained :

$$\theta_I\sqrt{\pi\rho\sigma\kappa}\left\{5\int_0^\tau t^{-\frac{1}{2}}dt + \int_\tau^T\left\{1 + 4\frac{(T-t)^2}{(T-\tau)^2}\right\}t^{-\frac{1}{2}}dt\right\} \quad . \quad . \quad (14)$$

The integrations (11) and (14) lead directly to equations (4) and (5).

Preheating the Ladle.

Consider first the case of a ladle of which the refractory lining is originally at zero temperature. Let the surface be raised to a temperature θ_l and maintained at that temperature for time t_0, then filled with metal so that the temperature of the surface rises instantaneously to θ_I and remains at that value for time T'. T' is the time which the metal would have to stand in the full ladle to suffer the same drop in mean temperature as actually occurs during tapping and casting. The heat absorbed may be calculated by considering it as the sum of the heat absorbed as a result of maintaining the surface at θ_l for a time $t_0 + T'$ and that absorbed as a result of maintaining the surface at $\theta_I - \theta_l$ for time T', *i.e.* :

$$10R^2\sqrt{\pi\rho\sigma\kappa}\{\theta_l\sqrt{t_0 + T'} + (\theta_I - \theta_l)\sqrt{T'}\}.$$

But of this total the amount supplied during the preheating of the ladle is :

$$10R^2\sqrt{\pi\rho\sigma\kappa}\,\theta_l\sqrt{t_0}.$$

Thus, the total heat extracted from the steel is

$$10R^2\sqrt{\pi\rho\sigma\kappa}\{\vartheta_I\sqrt{T'} - \theta_l(\sqrt{t_0} + \sqrt{T'} - \sqrt{t_0 + T'})\}.$$

Equating this to :

$$10R^2\sqrt{\pi\rho\sigma\kappa}\{\theta_I\sqrt{T'} - p_1\theta_l\sqrt{T'}\}$$

it is found that :

$$p_1 = 1 - \sqrt{1 + \frac{t_0}{T'}} + \sqrt{\frac{t_0}{T'}},$$

where

$$T' = T\left\{\frac{47 + \dfrac{16n^2(4 + 3n)}{(1 + n)^2}}{75}\right\}^2 \text{ for free flow,}$$

or

$$T' = T\left\{\frac{11 + \dfrac{8n^3}{(1 + n)}}{15}\right\}^2 \text{ for uniform casting rate.}$$

It is generally sufficiently accurate to take T' as equal to $\frac{1}{2}(T + \tau)$.

In practice the heating is not so thorough as would be the case under the conditions considered above. It would, however, be more thorough than if heat were supplied at a constant rate such that after time t_0 the surface were at temperature θ_l. The rise of the surface temperature with time under the two conditions is shown in Fig. 4. The actual curve will fall between the two, as the rate of heat input is greater at low temperatures.

Consider a slab of thickness $2l$ in which the temperature gradient at the surfaces $x = 0$ and $x = 2l$ is maintained at $-c$ from time $t = 0$. The temperature at time t is given by :

$$\theta = c(l - x) - \frac{cl}{\pi^2} \sum_{n=1}^{n=\infty} \frac{(-1)^{n+1} + 1}{n^2} \cdot \cos\frac{n\pi x}{2l} \cdot e^{-\frac{n^2\pi^2a^2}{4l^2}\cdot t}$$

which gives :

$$\frac{\partial\theta}{\partial x} = -c + \frac{c}{2\pi}\sum_{n=1}^{n=\infty}\frac{(-1)^{n+1}+1}{n}\cdot\sin\frac{n\pi x}{2l}\cdot e^{-\frac{n^2\pi^2 a^2}{4l^2}\cdot t}.$$

In the limit, as $l \longrightarrow \infty$:

$$\frac{\partial\theta}{\partial x} = -c\left\{1 - \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{a^2 t}}}e^{-\xi^2}d\xi\right\}.$$

This is a tabulated function and the value of θ was plotted by graphical integration. θ was found to be of very similar form to :

$$\theta = \theta_l\left\{1 - \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{a^2 t}}}e^{-\xi^2}d\xi\right\},$$
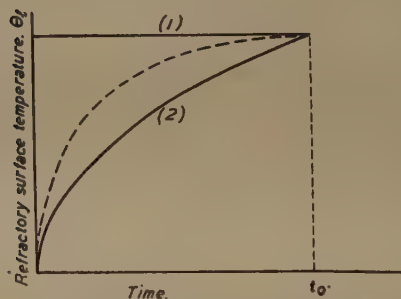
FIG. 4.—Rise of Temperature of the Inner Refractory Surface during Preheating.

and the two functions were most nearly identical after times which were in the ratio of 0·64 to 1. That is to say, if the rate of heat input is constant and the surface rises to a temperature θ_l in time t_0, then the temperature distribution is almost the same as if the surface had been maintained at a temperature θ_l for a time $0·64 \cdot t_0$.

The lower limit of p may therefore be expressed thus :

$$p_2 = 1 - \sqrt{1 + 0·64\frac{t_0}{T'}} + \sqrt{0·64\frac{t_0}{T'}}.$$

The values tabulated are the mean of p_1 and p_2. Actually p_1 and p_2 differ by less than 0·05 for all but the very lowest values of t_0/T'. Normal preheating times yield values in agreement within 0·03 ; p is therefore reliable to about 0·02.

DISCUSSION.

Mr. D. A. OLIVER (Messrs. Wm. Jessop & Sons, Ltd., Sheffield) said it gave him great pleasure to open the discussion, as he had had the privilege of seeing the author develop the work described from quite small beginnings. The paper needed no defence, as the author had already outlined a number of apparently con-tradictory facts which had been harmonised by the theoretical approach that had been adopted. From the point of view of shop practice at the present time the work had some valuable practical applications. There was a need nowadays to economise on gas, and the gas-heating of the ladle, which was a straightforward and effective method of heating it, was a very wasteful way; and the problem faced them of how the steel was going to vary in teeming temperature if they did not heat their ladles sufficiently well by alternative methods. The paper would give some help in dealing with a problem of that kind by making it possible to say how much greater the drop would be if the ladle was not properly heated, or if it was heated to only a given fraction of the normal degree.

The paper was also of great interest in connection with making foundry work more scientific. Mr. W. J. Dawson, Chairman of the Steel Castings Research Committee, had recently initiated a research on temperature survey and control in the foundry. The question of the ladle cooling of liquid steel was part of that story, and foundrymen would be gratified to learn that with certain ladles, not remote from those used in practice, surprisingly uniform tem-peratures were obtainable in practice, even after appreciable periods during which the steel had been in the ladle. That was a fact which he thought was going to augur well for better control in the foundry. It was now known that reasonably good uniformity of temperature in the furnace could be obtained, and it was known that in the ladle it was extremely poor, looked at from the point of view of distribution; but it was known also that the uniformity of the issuing stream, judged by ordinary practical standards, could be very good, even after comparatively short periods of holding the steel in the ladle.

Dr. C. H. DESCH, F.R.S. (Vice-President; Iron and Steel Industrial Research Council), remarked that the paper was of very great practical importance from the point of view mentioned by Mr. Oliver; now that so much more attention was being given to the production of high-quality steel castings, it was important to have a uniform casting temperature over a series of castings, and that could be obtained, as the author had shown, by tapping from the bottom of the ladle, whereas it was not possible to get anything of the kind by lip pouring.

When he first read the paper, he was surprised to find that

result. It showed that in a ladle of ordinary size the whole formed a single convection system; that was to say, there was liquid metal flowing downwards all round the periphery, which meant that there must be a rising current in the centre. If one looked at a ladle of hematite cast iron which was being cast, one saw a hexagonal pattern of kish on the surface, and that meant that there was a number of convection cells. In each case the metal rose in the centre and fell round the periphery. That was first noticed, he believed, by Professor James Thomson nearly a hundred years ago. Professor Thomson was out for a walk one day and passed a cottage with a tub of soapsuds standing outside. He saw the hexagonal pattern and went back and worked out the mechanism of it very correctly. Many years afterwards it was worked out by Bénard in France, who found the same thing, using waxes. Repeating a number of experiments of that kind, the speaker was able to measure the actual difference in temperature between the centre and the periphery of these cells by putting in very fine differential thermocouples, and it was found that there was actually a rising column of hot liquid in the centre and a falling column of cool liquid round the periphery.

When it came to a ladle of the size dealt with by the author, however, instead of breaking up into a number of convection cells, the whole content of the ladle formed a single cell, according to the author's work; and it seemed that the reason for that must be that the surface was covered with a layer of slag. In the case of the ladle of cast iron there was no layer of slag on top, and therefore the cooling took place largely by contact with the atmosphere. The reason for this uniformity in the ladle of steel, in his view, was that the cooling from the surface was almost entirely prevented by the layer of slag. That was an interesting point. The evidence given in the paper was quite clear, and there was a perfectly simple set of tables. The mathematics used to arrive at them were not so simple, but the conclusions were simple, and it was possible in any steel foundry, with the aid of the immersion pyrometer, which the Steel Castings Research Committee and a Sub-Committee of the Ingot Committee had done so much to develop, and of the author's tables, to have almost perfect control of temperature in steel casting.

Dr. R. J. SARJANT (Messrs. Hadfields, Ltd., Sheffield) expressed his interest in the paper. To see the probability integral applied to what was, after all, a very difficult practical problem was very gratifying, he said, to anyone who had tried to apply methods of that kind to steelworks practice for a good many years, and he thought that the author was very much to be congratulated on having tackled a difficult problem and on showing a very good measure of progress in the results obtained.

The first thing that they did in his own firm on seeing the paper

was to look at the Table of results and to compare them with their own results. He had brought with him two diagrams of results which they obtained from their own practice, applied to the results as determined by the use of the author's Table, and he had been gratified to find, on plotting the observed temperature drop obtained from the use of optical pyrometers, and the difference between the observed and the calculated temperature drop, that there was a general relationship; but the difference in one set of values went up to 30°, and in another set, where they could not be satisfied that their data were so good, it went up to as much as 70° C. He would not put that evidence forward as showing that the data in the Table were necessarily at fault, because it was necessary to make so many assumptions in applying work of the kind in question. For example, in their case they had to assume the temperature of the ladle. They had no right to assume that this temperature of the ladle was more accurate than the figures which the author had developed. The author had given a factor of 0·64 for the preheating of the ladle. He knew from many experiments which he had made in heating refractory substances that a factor of that kind was obtained when the probability integral was used. But the factor did not always run out at 0·64; it ran out at anything from 0·3 up to 0·8, and it depended very much on the shop conditions involved. In open-hearth ladles one had the use of the brazier or gas, and in the electric furnace practice applied in the case of the results under discussion the ladle was inverted over a coke fire and heated up to a bright red heat.

With all these variations, a list of probably a dozen factors could be compiled, which at some time or other were likely to introduce errors into the estimations. To mention a few, there were the rate of heating of the ladle, already referred to, the ladle wear, the fact that refractories changed their physical characters and probably also their thermal constants in the course of their life, and the change in the surface of the ladle.

It was necessary to take into consideration the fact that when a liquid was cooling and losing heat into a solid, the main factor which governed the heat transfer was the film coefficient of heat transfer at the interface between the liquid and the solid, in this case the liquid steel and the refractory material. No one knew what that coefficient was. The author assumed that the metal would follow a square-root law, and that the casting rate would be proportional to the depth of the metal in the ladle, but that did not always happen in practice. Again, the question of uniformity of temperature in the ladle did not always come in. There were plenty of cases where one obtained a uniform heat from the ladle. The idea of the metal being cold at the bottom was well known and well established. He did not think that anyone would dispute that there was some form of convective flow down the side which brought the cold metal to the bottom, but the change of temperature during

casting did vary considerably. It would generally start at a low figure, reach a maximum perhaps one-third of the way through the heat, and fall off during the rest of the casting.

Other workers would not necessarily find that the author's Table fitted their practice ; the conductivities and the thermal constants were bound to be different.

He could not agree that slag was necessarily a perfect insulator, because a great deal depended on its composition and character. Whether one obtained a good heat or not definitely depended on the character of the slag, and the discrepancy between the figures which they had been able to get at Messrs. Hadfield's and those derived from the author's Table was possibly due, not necessarily to errors of their assumptions in applying the figures they had used, but to the question of slag insulation. It might be a minor point compared with the chill in the refractory lining of the ladle, and he believed that that was perfectly true ; but it was one of those confusing factors which came along at the wrong time and upset one's plans.

Mr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) said that this was the first time in a long experience in steelmaking that he had been able to form a clear picture of the way in which skull was produced in the ladle. He had always imagined that it formed towards the end of the teeming, but the author had presented strong evidence to show that, if a cast was on the cool side, steel could be deposited on the bottom of the ladle during almost the whole period of teeming. The difficulty sometimes experienced in keeping the nozzle open was thus satisfactorily explained.

CORRESPONDENCE.

Mr. J. E. RUSSELL (English Steel Corporation, Ltd.) wrote that any paper which dealt with the application of the precise methods of mathematics to the cruder processes of metallurgical practice presented special problems to the critic. It was too easy to pick holes in the mathematical approximation to the actual physical conditions and to say that such-and-such assumptions were untrue, forgetting that simplifying assumptions were essential if the problem was to be brought within the scope of practicable mathematics, and that results were required, or could be confirmed, only within certain fairly wide ranges of accuracy. Only too frequently was criticism of this type of paper carried to such fastidious extremes that basic principles were drowned in a confused welter of detail. Thus, referring to Mr. Land's paper, one should not stress too heavily the losses of heat between tapping and casting due to the flow of the metal down the launder, and the subsequent flight through the air, or the losses from the surface due to both radiation and convection before the slag arrived to " blanket " the metal.

Mr. Land was in daily contact with the various problems of liquid steel temperatures, and since he omitted consideration of these details one must accept his implied view that these losses were negligible in comparison with the losses due to the refractory walls of the ladle.

There were, however, two points which he wished to raise :

(1) In his numerical example on p. 163 P, Mr. Land referred to the " drop in temperature under standard conditions." Actually, Table I., which presumably referred to these " standard conditions," must have been worked out from either equation (8) or (9), assuming some non-zero value of n^2, about 0.17–0.18 if he used equation (9), and about 0.35–0.36 if he used equation (8). It would be interesting to know which of these he used, and why he considered the one or the other of these two values of n^2 ($= \tau/T$) to be in any way " standard," or why a " standard " holding time τ should be different for free casting and for a uniform casting rate.

(2) It might have been better if Mr. Land had left equations (4) and (5) in their more general form, without working out the factor $1/27.8$. Actually, this factor contained ρ' (taken equal to 7.5) and equations (4) and (5) were not applicable to *any* molten metal in the ladle, as they appeared to be in the form given, since ρ' was retained in the denominator. It might have been less misleading if Mr. Land had left them as :

For free casting under gravity :

$$\theta_T - \theta_C = \frac{1}{15}\theta_I \sqrt{\frac{\rho\sigma\kappa}{\pi}} \, \frac{T^{\frac{1}{4}}}{W\,\rho'\sigma'} \left[\frac{2\pi\rho'}{2240 \times 453.6}\right]^{\frac{1}{4}} \left\{47 + \frac{16n^2(4+3n)}{(1+n)^2}\right\}.$$

For casting at a uniform rate :

$$\theta_T - \theta_C = \frac{1}{3}\theta_I \sqrt{\frac{\rho\sigma\kappa}{\pi}} \, \frac{T^{\frac{1}{4}}}{W^{\frac{1}{2}}\rho'\sigma'} \left[\frac{2\pi\rho'}{2240 \times 453.6}\right]^{\frac{1}{4}} \left\{11 + \frac{8n^2}{1+n}\right\}.$$

Apart from these points, Mr. Land had made a useful contribution to the study of liquid steel temperatures. It would be interesting to see his work extended to the consideration of multiple-furnace casts, where the ladle used for tapping the first furnace was refilled with steel from one or more other furnaces while casting was going on. The value of T for the first ladle would become very large, and the assumption of a semi-infinite solid for the refractories might become too crude. However, Mr. Land might disagree with this, since he quoted values of the temperature drop for a 40-ton cast up to a tapping-to-casting time of 2 hr., which was nearly twice the time required for a three-furnace cast of 150 tons or more.

Dr. Eng. W. WRAZEJ (Poland) wrote that, with regard to the mechanism of the cooling of steel after it had been tapped into the

ladle, described in Mr. Land's paper, he agreed with this point of view.

The figures concerning quantities between 5 and 10 tons of steel for holding periods in the range between 5 and 12 min. were the same (so far as he could remember) as he himself had ascertained. The time of holding the steel in the ladle for such quantities as he mentioned above was adjusted after the tapping temperature had been measured. The holding time was from 6 to 12 min. In some cases, when the steel was tapped cold, it was held for only 5 min., but in exceptional cases, when the steel was very hot, the holding time was 15–16 min.

The figures given in Tables I., II. and III. were of great importance. By means of these Tables, it would be possible to determine in all cases the time of holding, which depended on the tapping temperature, on the quantity of steel and on the ladle condition (preheating treatment). It was not difficult to arrange the preheating of the ladle so that it would have the same preheating temperature every time.

It would now be possible to reap the full benefit of holding the steel in the ladle without fear of its freezing. In his opinion, this procedure should be the custom in every steelworks. It offered so many advantages that it should be given a prominent place in steel research.

He knew of many cases where this simple treatment of steel had produced excellent results. In a good foreign steelworks he had seen that the steel was held in the ladle, and he applied it, as mentioned above, in many cases, with the best results. The holding of steel in the ladle had the following advantages :

(1) It enabled all absorbed gases to escape easily.

(2) It rendered possible the coagulation of slag particles, which could then rise to the surface. This was very important when deoxidation was not carried out long enough before tapping.

(3) The cooling of the steel which took place while held in the ladle and the uniform temperature of the steel being teemed were of special advantage in cases where overheating of the steel could easily occur (for instance, in high-frequency or electric arc furnaces).

Dr. Wrazej wished to take this opportunity of recalling the research which he had conducted on the subject of flakes in alloy steels.[1] As the chief means of avoiding the formation of flakes, he had recommended—after having proved the presence of hydrogen—that the steel should be held, and that procedure, enabling the gases to escape, gave good results.

[1] W. Wrazej, " The Causes of the Formation of Flakes in Steel and Works Observations," *Hutnik*, 1936, vol. 8, pp. 263–273 : *see Journal of the Iron and Steel Institute*, 1937, No. I., p. 17 A.

The presence of impurities and segregations caused, for example, the tendency to lamination of homogeneous armour-plate to increase; by holding the steel in the ladle, the amount of the impurities and consequently their influence were decreased.

In other cases also, the presence of slag, as was well known, was undesirable. Steels with high alloy contents, if teemed at a very high temperature, were inclined to produce cracked ingots; further, the same steels teemed at a lower, though still high, temperature were again likely to crack unless the speed of teeming was regulated so that the steel poured from the ladle was of uniform temperature.

The foregoing few examples showed the importance of further researches on this subject.

By using the figures given by Mr. Land and by measuring the tapping temperature it would be possible to estimate all the necessary data for holding the steel in the ladle, which could be adapted to the special working conditions and needs in every steelworks.

This treatment of steel, easy of application, gave so many important advantages that it should be adopted and further investigated in every steelworks, especially in war-time, when the working conditions (inferior scrap, &c.) were abnormal and the production must be at the highest in both quality and output.

Mr. W. H. SALMON (Messrs. Hadfields, Ltd., Sheffield) wrote that, with regard to the mechanism of convection currents shown by the author's experiments, it had been observed that optical-pyrometer readings taken on the stream issuing from the nozzle of a bottom-stoppered ladle indicated that the temperature of the steel gradually rose 10–15° C. during the casting of the first two or three ingots or castings, and then gradually fell while the rest of the heat was being poured. Did Mr. Land think that this apparent increase in temperature was due to the hot-metal current down the inside walls of the ladle, as indicated by his visual observations made on medicinal paraffin, or to a proportion of slag emulsion being drawn down from the upper layers of the steel, thus increasing the emissivity of the molten steel from, say, 0·40 to some higher figure approaching 0·65 ? Had Mr. Land any evidence from the immersion readings that he had taken in tundishes that this was a true rise in temperature or an apparent rise due to the high emissivity of the entrained slag particles ? The writer had previously assumed that the lower temperatures taken when the nozzle was first opened were due to the chilling action of the ladle bottom, and that a more marked rise in temperature was observed when the ladles were not sufficiently preheated.

With regard to the greater range of cooling experienced with lip-poured ladles, this feature was of benefit to foundries making a wide variety of castings from one heat. The first shanks were used for thin castings of up to 10 or 15 lb. each, and later for slightly

heavier castings, about 56 lb. each, after the steel had become too cold to run the thinner sections. When the steel would shank no further, larger castings of from 1 cwt. to 20 cwt. or more were poured over the lip as the steel was cooling.

The use of lip-poured ladles enabled one heat of steel to be used for many different sections of castings at the optimum temperature for running each section. On the other hand, thanks to the slower cooling of the steel in bottom-poured heats, the heaviest castings were poured early in the heat, and the steel was still fluid enough to take the spare moulds at the end of the heat in small quantities so that when all the steel was cast and the slag came, the last mould, which was sometimes cast short, was only of insignificant weight.

Mr. N. F. DUFTY (Brymbo, Denbighshire) wrote that in the first place the author must be congratulated on the ability with which he had applied pure mathematics to a subject which bristled with practical difficulties and unforeseen variables.

The writer wished to ask Mr. Land a few questions. On p. 160 P it was stated that " if casting is allowed to take place freely under gravity the casting rate will be proportional to the square root of the depth of metal in the ladle." As every steelmaker knew, the nozzle did not maintain its original size. If the metal was hot, the nozzle opened out and the casting rate increased to a maximum, and then fell off as the depth of the metal in the ladle decreased sufficiently to overcome the effect of the increased nozzle size. On the other hand, if the steel was cold, the metal skulled in the interior of the nozzle, decreasing the aperture and lowering the casting speed. Often the interior of the nozzle was quite clear and the casting speed decreased owing to skull formation in the nozzle well. Was it possible to calculate the critical teeming temperature at which the nozzle neither opened out nor skulled up ?

There was no doubt that the skull on the bottom of the ladle formed very quickly, and usually the teemer could feel the skull on the nozzle well when he shut off on the first ingot. This was frequently the cause of dribbling, bad shut-off and similar troubles. An inadequate slag blanket could also cause skulling at the end of the teeming period. Several cases had occurred in arc-furnace practice when the slag had for some reason been very viscous and largely remained in the furnace after tapping, leaving the metal in the ladle with a very unsatisfactory covering. A heavy skull had resulted in every case, but the interesting point was that the skull had usually been in two distinct layers, showing that the lower one was formed first and the other at the conclusion of the teem. Another instance that confirmed Mr. Land's investigation was a 2-ton heat of stainless steel which was tapped very cool; most of the metal was teemed with the aid of oxygen to open the

nozzle, but the skull was on the bottom, all the way up the sides and also on the top, probably owing to the thin, low-bulk slag.

In practice the steel on the bottom of the ladle solidified more quickly than the metal in the upper portion of the ladle. Holding the steel in the ladle seemed to cause skull formation without cooling the main body of the metal to any extent. The best method of dealing with a heat that was known to be a little too warm appeared to be to tap very slowly. This, of course, was only possible with tilting furnaces. About a third of the ladle was filled at a reasonable speed or a skull was formed on the bottom, owing to the large ratio of the refractory-metal contact area to the weight of metal in the ladle. The remainder of the steel could be tapped very slowly without any danger. Could Mr. Land offer any explanation of this?

When duplex nozzles such as the Fawcett-Battie were used, another phenomenon was occasionally encountered. A cast could be tapped very cool and the skull could be felt when shutting off. The nozzle skulled up and the casting speed dropped; on account of this the smaller outer nozzle was removed after teeming perhaps only one or two ingots, and the remainder were teemed through the larger ladle nozzle, say, $1\frac{1}{2}$–2 in. in dia. Such an acceleration of teeming speed might bring the warmer metal from the upper part of the ladle before it had cooled to any great extent and the skull which was initially on the bottom was removed. This might be purely a temperature effect, but was more probably the combined effect of the hotter metal from the upper portion of the ladle and the rapidity of the flow through the large nozzle.

Concerning the important point of fuel saving, provided that the ladle had been thoroughly dried out after rebricking or patching, a flash heating of 10–20 min. in the case of a ladle holding 7–15 tons would suffice. The surface temperature of the refractory lining might be quite high, a bright red heat, but the depth of penetration could not be very great with so short a heating time. Quite apart from saving fuel, a short heating period would not raise the temperature of the stopper rod to a dangerous level. Except when the ladle was inverted over the source of heat, prolonged heating with a short flame would only result in overheating of the stopper rod and inadequate heating of the bottom of the ladle.

In conclusion, the writer expressed the hope that Mr. Land would continue his investigations, not only on the cooling of liquid steel in the ladle but also on similar problems affecting the teeming of liquid steel.

Dr. F. H. SCHOFIELD (Freshwater, Isle of Wight) wrote that Mr. Land was to be congratulated on the manner in which he had tackled a most intricate problem. It had, of course, been necessary to make drastic simplifying assumptions to permit of a compara-

tively simple treatment, but these were based on experiment and practical experience, and it was difficult to suggest any better. Particularly valuable was the clear presentation of the main results in tabular form. It was hoped that this would stimulate others to undertake the observations necessary to check the theory under a wide variation of conditions.

An interesting point which emerged from the paper was that already Mr. Land found himself handicapped by the lack of data on the physical properties of liquid steel. This lack would become acute if, as might be anticipated, the next stage of theoretical development was to be a study of the temperature distribution in the ladle charge. For this and other reasons, the time was perhaps ripe for considering the investigation of constants of liquid steel such as specific heat, viscosity and the closely related properties of thermal and electrical conductivity.

Mr. D. MANTERFIELD (Messrs. Steel, Peech and Tozer, Sheffield) wrote that comparisons had been made on a few casts where " going-on " temperatures and tundish temperatures had been observed by means of the immersion pyrometer. To obtain an approximate tapping temperature, corrections were made to the " going-on " figures in proportion to the weight of cold finishings added. The ladles were preheated before use and the weight of metal was 82 tons.

The details were as follows :

Cast.	Temperature at—	Temp. Reading.	Temp. Decrease.	Time between Tapping and Tundish Temp. Readings
31/373.	Going on	1611° C.		
	Approximate tapping	1597° C.		
	Last tundish	1538° C.	59° C.	30 min.
30/4441.	Going on	1584° C.		
	Approximate tapping	1573° C.		
	Average of 5 tundishes	1535° C.	38° C.	(First tundish) 15 min.
30/4460.	Going on	1602° C.		
	Approximate tapping	1586° C.		
	First tundish	1529° C.	57° C.	15 min.
31/396.	Going on	1629° C.		
	Approximate tapping	1600° C.		
	Average of 3 tundishes	1547° C.	53° C.	20 min.
31/398.	Going on	1612° C.		
	Approximate tapping	1576° C.		
	First tundish	1535° C.	41° C.	15 min.

According to Table I. of the paper there should be a decrease of about 49° C. in 30 min. with 82 tons of metal. There appeared to be a considerable spread of temperature decrease in the cases quoted above. Curiously enough, the average fall in temperature, taking no count of time, was 49° C.

It should be stated that no surface ladle temperatures were observed and some correction would be necessary for this factor. Furthermore, the temperatures quoted would include any cooling effect of the tundish as well as the ladle. An isolated experiment to determine this effect was made on cast 31/396. As soon as the tundish was full the temperature recorded was 1543° C.; when the moulds were full the temperature in the same tundish was 1551° C.

Confirmation had been obtained of Mr. Land's remarks on p. 164 P that " a cool layer is formed in the bottom half of the ladle and this acts as a reservoir from which the metal is drawn during casting." Two examples followed :

Cast.	Tundish.	Temperature.	Time.
30/4441.	First	1539° C.	12.45 P.M.
	Second	1531° C.	12.50 P.M.
	Third	1531° C.	12.55 P.M.
	Fourth	1539° C.	12.58 P.M.
	Fifth	1536° C.	1.02 P.M.
31/396.	First	1538° C.	4.0 P.M.
	Second	1543° C.	4.07 P.M.

As a matter of interest, a series of three ladle temperatures taken at one-third full, two-thirds full and full ladle, on cast 32/7744, gave the following results :

Temperature at—	Temp. Reading.	Time.
Going on	1588° C.	...
Approximate tapping	1580° C.	7.38 P.M.
Ladle one-third full	1555° C.	7.41 P.M.
„ two-thirds full	1559° C.	7.43 P.M.
„ full	1542° C.	7.45 P.M.

It would appear that, considering the unknown factors in the cases quoted, there was a fair measure of agreement between the calculated and the actual temperatures.

It should be stated that two other casts (not quoted above) showed a decrease of 67° C. and 82° C. These tundish temperatures, however, were taken on the first tundish as soon as it filled and would therefore be unreliable indications of the average ladle temperature.

The practical application of Mr. Land's painstaking work would be followed with interest.

AUTHOR'S REPLY.

The AUTHOR replied that he would like to record his thanks to all those who had contributed to the discussion and to the correspondence. A great deal of interesting and valuable information had been put forward, which would greatly assist all who were active in bringing the temperature of liquid steel under fuller control.

He was glad that Mr. Oliver stressed the practical aspect of

the paper. In bringing the temperature of the liquid steel in the
foundry under closer control there would be a very practical need
to understand what happened to the steel in the ladle. His object
in presenting the paper was to provide a rational basis for the
correlation of observations of casting temperatures. In this way
it should be possible to make predictions on the sound basis of
past experience, taking into account the many variables which
affected the degree of cooling.

Dr. Desch's remarks on the formation of convective cells were
very instructive. It was particularly interesting to find that the
hexagonal cells occurred in a ladle of cast iron. As Dr. Desch
pointed out, the ladle of steel cooled under very different conditions,
owing to the insulating layer of slag on the surface. It appeared
that the conditions prevailing in the steel resembled more closely
those in the small-scale experiment described in the paper, in which
the cooling occurred chiefly at the sides. The question could only
be finally decided by experiment, and it was hoped the newly formed
Foundry Steel Temperature Sub-Committee would be able to throw
more light on the subject.

Dr. Sarjant's comparison of figures deduced from the Tables
with the results of optical-pyrometer readings was useful, but the
author felt sure that he would agree that one would be in a much
better position to examine the validity of the figures quoted in
the Tables when a good body of data obtained by the quick-im-
mersion method had been accumulated. He readily agreed that
there would be many disturbing factors which would have to be
taken into account in estimating the temperature drop. The most
important was probably the thickness of the slag. There were
occasions when the slag layer was abnormally thin and allowance
must then be made for additional cooling.

He was particularly indebted to Mr. Russell for the care that
he had taken in checking the mathematics. He had pointed out
in a private communication that in the advance copy of the paper
there was a slip in the derivation of equations (8) and (9). Happily
the equations and the Tables were unaffected by the correction,
and it had proved possible to assign to the thermal constants values
which were in much more satisfactory agreement with those usually
accepted for the type of brick used to line ladles. The paper as
now printed was correct.

The first point which Mr. Russell raised was fairly easily ex-
plained. Table I. was arranged so that it could be used for the
normal conditions of works practice with a minimum of correction.
Equations (8) and (9) were identical except for the two factors :

$$\left(47 + \frac{16n^2(4 + 3n)}{(1 + n)^2}\right) \text{ and } \left(55 + \frac{40n^2}{(1 + n)}\right).$$

Table I. was drawn up assigning a value of 60 to either of these
factors. It naturally corresponded, as Mr. Russell pointed out,

to different values of n in the two cases considered. Table II. was then calculated from the two functions of n mentioned above. Mr. Land agreed that equations (4) and (5) were of more general application in the form quoted by Mr. Russell.

Dr. Wrazej had provided many cogent reasons for holding steel in the ladle before casting. A warning should perhaps be added regarding the use of the Tables. Even though the Tables might show that the average casting temperature would be above the solidus point of the steel, it should not be assumed that the metal would not freeze in the ladle. The Tables showed only the average temperature of the casting stream. It was well known that the first few hundredweights of metal were frequently 20° C. cooler than the remainder of the cast, owing to the cooling effect of the ladle bottom, and it was important to make an adequate allowance for this initial cool layer.

Mr. Salmon raised the question of the uniformity of temperature of the casting stream. The figures at present available were not fully conclusive, but suggested that the variation observed was a true variation of temperature rather than a variation of emissivity. Table A showed two sets of temperatures taken by the quick-immersion method in the troughs of eight 3-ton ingots cast from a 25-ton ladle. The optical pyrometer reading on the casting stream in each case was also given. The readings in each case were remarkably uniform and there was little sign of changing emissivity.

TABLE A.—*Two Sets of Quick-Immersion Thermocouple Readings in the Troughs of Eight 3-Ton Ingots Cast from a 25-Ton Ladle.*

Ingot No.	1.	2.	3.	4.	5.	6.	7.	8.
				First Set.				
Dip temp. in trough. ° C.	1533	1533	1532	1533	1534	...	1533	{ 1533 1535
Optical-pyrometer reading on casting stream. ° C.	1415	1420	1415	1420	1420	1415	1415	1410–1415
				Second Set.				
Dip temp. in trough. ° C.	1550	1549	...	1549	1550	1549	1546	1556
Optical-pyrometer reading on casting stream. ° C.	1415	1415	1415	1410	1410	1415	1415	1410

Further evidence was provided by the fact that holding the metal in the ladle resulted in a much better uniformity of casting temperature. The following optical pyrometer readings were taken on a series of 14 small ingots cast from a 3-ton ladle after holding in the ladle for 2 min.; the time from commencing to finishing casting was $9\frac{1}{2}$ min. :

Ingot No.	2.	5.	8.	11.	13.
Optical-pyrometer reading in casting stream. ° C.	1370	1360	1355	1345	1345

The previous day a similar heat was cast under similar conditions, except that it was tapped 20° C. hotter and held in the ladle for 11 min. before casting was commenced. The casting occupied 6 min., and the temperature of the casting stream was now extremely uniform, being 1360° C. on each ingot after the first, on which no observation was made.

Mr. Dufty's contribution was full of interesting practical points. The opening-out of the nozzle was one of the factors to which the mathematician must turn a blind eye; the error introduced would, in any case, be very small. The mechanism of skull formation was a very interesting problem, which might be capable of fuller explanation when we had more knowledge of the physical properties of liquid steel. It would be very unwise to attempt to build too large a superstructure of theory until the first deductions had been more fully examined experimentally. Regarding the slow tapping of a heat that was known to be too hot, Mr. Land suggested that there were two important contributory factors. In the first place, so long as metal was being tapped into the ladle, the metal in the ladle was in constant movement and the formation of local cold spots was avoided. Secondly, the rate at which heat was extracted from the metal by the refractories fell very rapidly with time and would have reached a much safer value by the time the tapping speed was reduced. The values of the constant p quoted on p. 161 P showed that for a normal 7–15-ton cast, a ladle preheated to 900° C. in 15 min. would be as effective as one heated to 600° C. in 3 hr. Provided that the means of rapid heating were available, this would probably suffice in many cases, and would result in a large saving in fuel.

The author wished to thank Dr. Schofield for his kind remarks, and agreed that a knowledge of the physical properties of liquid steel was now becoming very necessary. It might be that one of the Institute Research Committees would be able to initiate a survey of such properties.

Mr. Manterfield's comments were very much appreciated, particularly the further experimental data which he put forward. The data bore out very well the author's own observations on tundishes. The two temperature measurements taken immediately after filling the first tundish supported the opinion that the first metal cast was some 20° C. cooler than the remainder. This was presumably because the first metal cast was of necessity drawn exclusively from the bottom layer in the ladle, whereas metal cast later was more representative of the whole cool reservoir, as was observed in the experiment with paraffin. The temperatures taken in the ladle during tapping provided evidence of a fresh kind, and when these could be supplemented by launder-stream temperatures they should prove very valuable.

THE APPLICATION OF SPECTROGRAPHIC METHODS TO THE ANALYSIS OF SEGRE-GATES.[1]

By F. G. BARKER, F.I.C., J. CONVEY, Ph.D., and J. H. OLDFIELD
(The Bragg Laboratory, Admiralty Inspection Department, Sheffield).

(Figs. 1 to 8 = Plates XVIII. to XX.)

Paper No. 7/1941 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee).

Summary.

Reference is made to preliminary experiments which showed that routine methods of spectrographic analysis were not applicable to the quantitative analysis of segregates without some modification. Further experiments made with standard graphite electrodes, silver electrodes of various shapes, and various spark gaps to reduce the area affected by sparking are described, also other variations in procedure which were found necessary to increase the line density of the spectrum to permit of estimations being made from a single exposure. Conditions are stated under which the elements silicon, manganese, nickel, chromium, molybdenum and vanadium can be estimated from one exposure of 15 sec. The diameter and depth of the crater formed under these conditions are approximately 0·012 in. and 0·0007 in., respectively, and the weight of metal actually involved in the test is approximately 0·000005 g. It is shown that tests on small bars of nickel-chromium-molybdenum steel give reproducibility of a satisfactory order, and that tests on specimens from large forgings of nickel-chromium-molybdenum and nickel-vanadium steel containing segregates give higher average values for all elements on the segregates than on the normal metal, the greatest percentage increase occurring for manganese, molybdenum and vanadium.

Experiments in hand to obtain continuous spectrograms showing the variation in composition, if any, which exists within the segregates are also described.

It was shown in a paper [2] entitled " Some Applications of the Spectrograph to the Analysis of Ferrous and Non-Ferrous Metals " which was read before a Joint Meeting of the Sheffield Metallurgical Association and the South Yorkshire Section of the Institute of Chemistry on February 7, 1939, that it was possible by means of the spectrograph to obtain at least a qualitative estimate of the composition of metallic segregates. At that time, however, no

[1] Received April 18, 1941.
[2] F. G. Barker, *Journal of the Iron and Steel Institute*, 1939, No. I., p. 211 P.

systematic study of the problem had been attempted, and the work done was chiefly to show the extent to which the presence of segregates might influence the results of routine spectrographic analysis rather than to determine their actual composition. The segregates examined were large, and the technique employed was the same as that used for the routine spectrographic analysis of steel. The matter aroused some interest, and the author of the earlier paper was approached by the Chairman of the Inclusions Sub-Committee to pursue the matter further, and work out, if found practicable, a technique for the quantitative analysis of segregates. This was undertaken. From the results of early experiments it soon became evident that, if the method was to be applicable to any but large segregates, the technique employed for routine analysis would have to be modified so as to reduce the area affected by sparking.

The method employed for routine analysis involves the use of a graphite rod with the end shaped to an 80° cone, a 0·08-in. (2-mm.) spark gap, and six 10-sec. exposures on different parts of the sample superimposed upon one another to make a single spectrogram. The effect produced on a polished sample by sparking under these conditions is illustrated in Fig. 1, (a) and (b). The light central part consists of a crater having a diameter of approximately 0·04 in., and a maximum depth of approximately 0·001 in. It is frequently of irregular shape, as shown in Fig. 1 (b), owing to preferential or irregular sparking. In the immediate vicinity of the crater the surface has the appearance of being lightly etched, and around this there is a light-brown stain or deposit of oxide. The latter is readily removed by lightly rubbing on a damp polishing cloth, and the crater and halo then appear as shown in Fig. 2, (a) and (b).

It was thought that a reduction in the area affected by sparking might be obtained by a change in the shape of the electrode point and by the use of a material which would keep its point better than graphite. Of the metals (excluding rare ones), which are available for use, and are not commonly present in steel, silver appeared to be one of the most suitable, and a series of tests was made with electrodes of this metal, shaped as shown in Fig. 3.

Using the standard 0·08-in. (2-mm.) gap, only slight differences in the size of the crater and the halo were obtained with the different electrodes. The wire-pointed one, viz., No. 5, gave results inferior to those obtained with the one of graphite, the diameter of the crater and the corona being slightly greater. This was found to be due to irregular sparking caused by the spark climbing away from the tip of the electrode as its temperature increased during the period of sparking. This led to the development of the nipple-pointed electrode, No. 6. With this it was found that sparking was largely confined to the point, the heat developed there being dissipated in the body of the electrode more readily than with No. 5. The size of the crater formed with the nipple-shaped electrode was approxi-

PLATE XVIII.
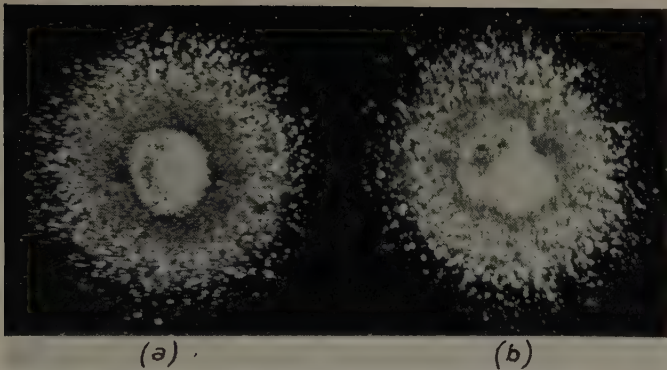
Fig. 1.—Crater and Halo obtained by Sparking with Graphite Electrode; (a) normal, (b) preferential sparking. Point, 80° cone. Spark gap, 0·08 in. Exposure 10 sec. × 8, oblique illumination.
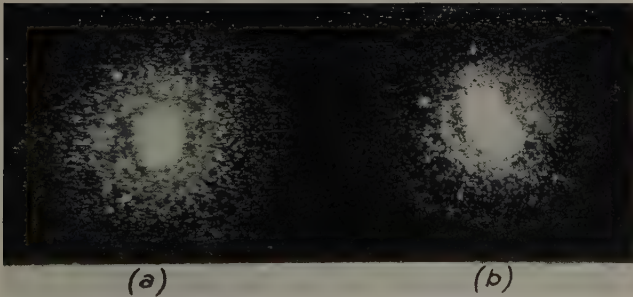
Fig. 2.—As Fig. 1, after lightly rubbing with damp polishing cloth. × 8, oblique illumination.
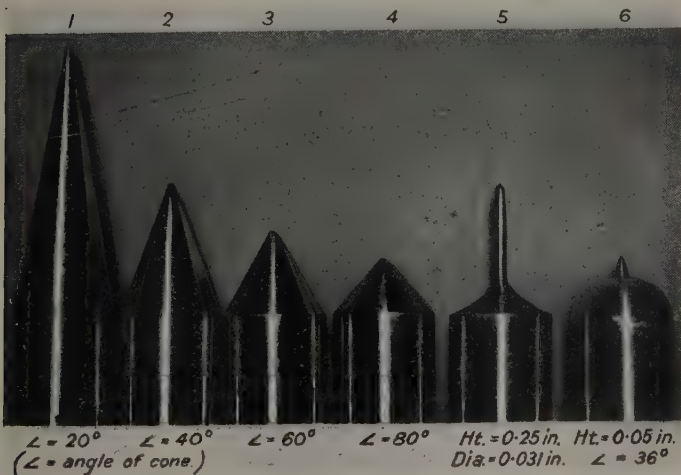
Fig. 3.—Shapes of Electrode Points used for tests to obtain reduced sparking area.

[*Barker, Convey & Oldfield.*
[*To face p.* 184 P.

PLATE XIX.
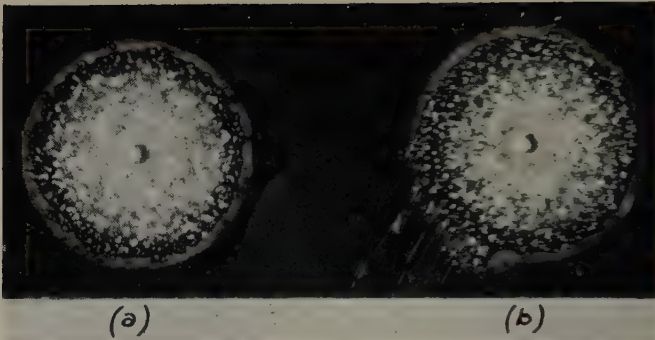
FIG. 4.—Craters and Halos obtained by Sparking with Nipple-Pointed Silver Electrode. Spark gap, 0·015 in. Exposure, 15 sec. × 8, oblique illumination.
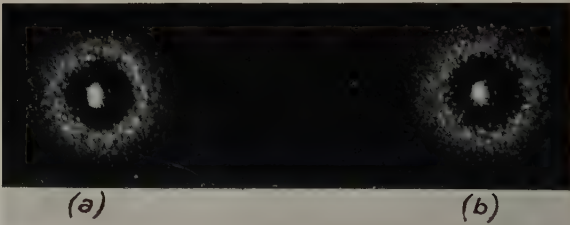
FIG. 5.—As Fig. 4, after lightly rubbing with polishing cloth. × 8, oblique illumination.

FIG. 6.—Transverse Section of Large Forging of Nickel-Chromium-Molybdenum Steel, etched to show segregates. × ⅗ (reduced to two-fifths linear in reproduction).

[*Barker, Convey & Oldfield.*

PLATE XX.
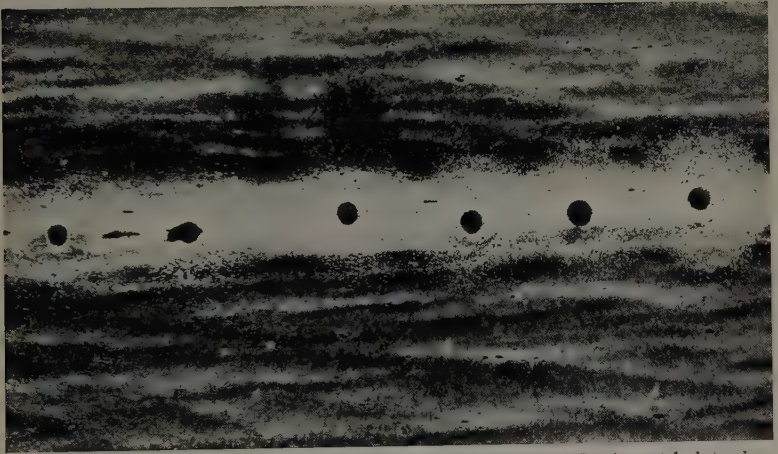
FIG. 7.—Longitudinal Section of a Nickel-Chromium-Molybdenum Steel Forging, etched to show segregate.   × 10.
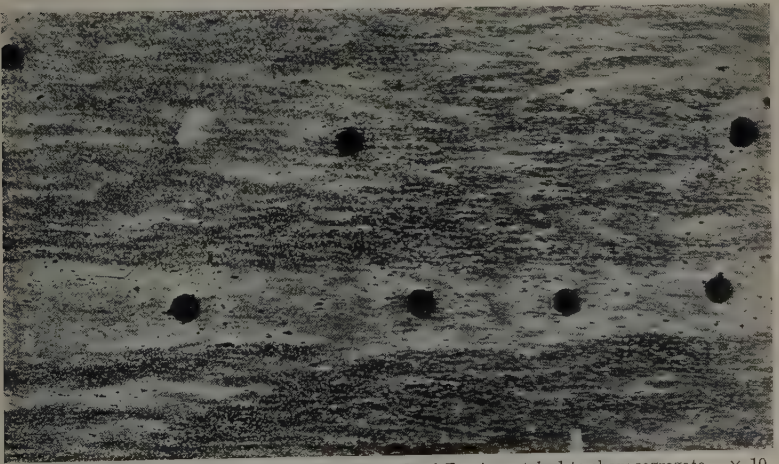
FIG. 8.—Longitudinal Section of Nickel Vanadium Steel Forging, etched to show segregate.   × 10.

(Figs. 7 and 8 reduced to four-fifths linear in reproduction.)
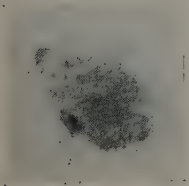
FIG. A.—Sulphide Inclusion in Nickel-Chromium-Molybdenum Steel.   × 900.
(*See* Whiteley's discussion.)

[*Barker, Convey & Oldfield.*

mately the same as that obtained with one of graphite, but it had a more regular form because of the lesser tendency of the spark to wander.

Tests were next made to determine the extent to which the sparking area could be reduced by a reduction in the spark gap. The same electrodes were used, and tests were made with gaps of various amounts down to 0·002 in. With a decrease in gap there was a decrease in the sparking area, and the best results with respect to uniformity of crater shape and halo were obtained with the nipple electrode, No. 6. All subsequent work was therefore done with electrodes of this type. With the smallest gap tested, *viz.*, 0·002 in., and a 15-sec. exposure, the diameters of the crater and halo formed with this electrode were 0·008 in. (0·2 mm.) and 0·088 in. (2·2 mm.), respectively.

An examination of spectrograms taken during the foregoing tests showed that, for given sparking periods, the line intensity diminished as the size of the gap was reduced, and that, with the 0·002-in. gap, lines of suitable intensity for the determination of the elements silicon, manganese, nickel, chromium, molybdenum and vanadium could be obtained with Ilford thin-film half-tone plates, which are used for routine analysis, only by making very long exposures or by superimposing many exposures upon one another —a course which would not be practicable except on large segregates. Further tests were therefore made, using the very much faster Kodak *B*10 Photoscript plate; this was found to possess great advantages over the other, and was used for all subsequent experiments.

A further reduction in sparking time was made possible by decreasing the distance between the arc and the slit of the spectrograph from 15·5 in., which is standard practice, to 4 in. It was also found that the sparking area could be further reduced if the electrode point were oxidised by sparking for 15 sec. before making the test; this, however, was not done in the position where a test was to be made. Spectrograms were prepared under these conditions, using a polished section of a 1-in. dia. bar of nickel-chromium-molybdenum steel on which macro-examination had not revealed segregation. With gaps up to 0·010 in., which gave the smallest sparking area, the spectrograms showed considerable variation in density. This was found to be due to slight variations in the position of the spark with respect to the optical axis of the spectrograph. The problem of alignment presented considerable difficulty, and it was ultimately found that a spark gap slightly greater than that which gave the smallest crater had to be accepted. From further experiments it was found that results which were satisfactory as regards reproducibility and sparking area were obtained with a gap of 0·015 in. and a single exposure of 15 sec. As a result of these tests, the following conditions were provisionally adopted for the analysis of segregates :

Wave band	.	.	.	2200–3000 Å.
Slit width	.	.	.	0·0006 in.
Distance of electrode from slit				4 in.
Spark gap	.	.	.	0·015 in.
Voltage	.	.	.	15,000.
Added inductance		.	.	Nil.
Upper electrode	.	.	.	Silver rod, nipple-pointed and oxidised by pre-sparking for 15 sec.
Plate	.	.	.	Kodak Photoscript B10.
Exposure time	.	.	.	15 sec.

The effect on a polished specimen of sparking under the above conditions is illustrated in Fig. 4. Fig. 5 shows the same specimen after lightly rubbing on a wet polishing cloth. The diameter of the crater is approximately 0·012 in. and that of the halo approximately 0·10 in. The depth of the crater as measured with a Société Genevoise measuring instrument, Type $MU-214B$, on which an accuracy of $\pm 0·00005$ in. is claimed, is 0·0007 in. The weight of steel corresponding to the volume of the crater is approximately 0·000005 g.

Standard curves, relating the log. ratio of the line intensity to the percentage of element present, which were prepared from chemically standardised steels, are shown in Figs. 9 to 13 ; each point on the curves is the average of ten spectrographic determinations.
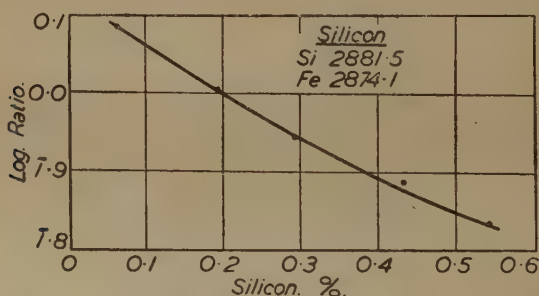
Fig. 9.—Graph for the Determination of Silicon from Spark Spectrograms.

Before commencing the examination of segregates it was necessary to establish whether the results of tests were dependent entirely on the spectral emission resulting from the main central discharge which forms the crater, or whether they were influenced by emission from the zone around the crater which has the appearance of a halo. The following tests were therefore made. A $\frac{5}{8}$-in. hole was drilled and ground in the centre of a piece of mild steel, $1\frac{1}{4}$ in. square by 1 in. thick, which did not contain more than traces of nickel, chromium and molybdenum. A piece of nickel-chromium-molybdenum steel was ground slightly taper to make a tight fit in

the mild-steel block, and was forced in under a hydraulic ram. The face was ground, polished and very lightly etched.   A number of spectrograms were then prepared by sparking on the mild steel in such positions that the resulting halo overlapped the alloy steel
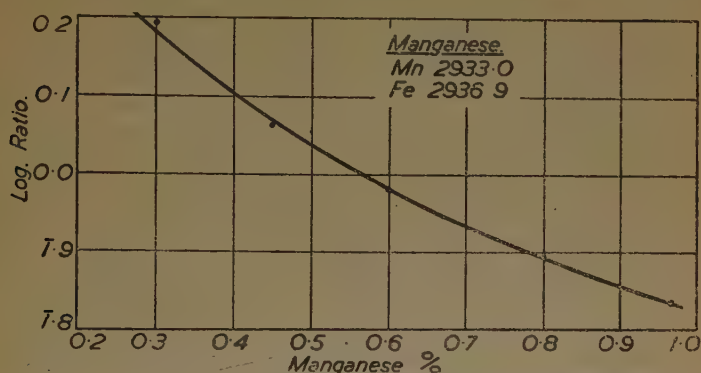
FIG. 10.—Graph for the Determination of Manganese from Spark Spectrograms.
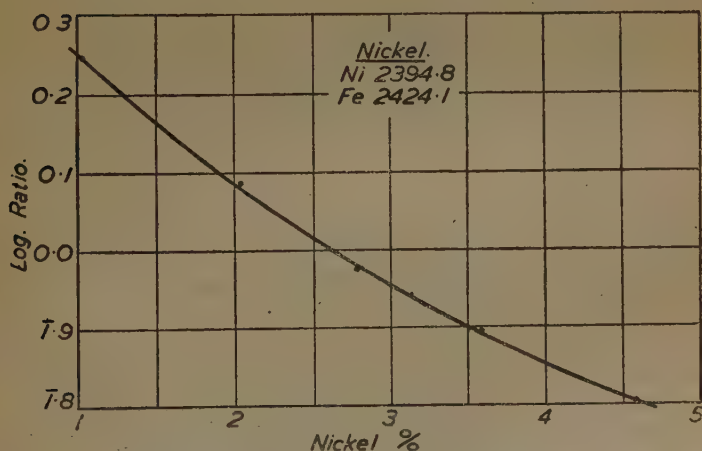
FIG. 11.—Graph for the Determination of Nickel from Spark Spectrograms.

by various amounts.   An examination of the spectrograms showed that not more than faint traces of the alloy elements appeared until the edge of the crater was at the actual junction of the two metals, thus establishing that emission from the halo does not influence the results of tests.

An examination of a number of segregates occurring in large forgings of nickel-chromium-molybdenum and nickel-vanadium steels was next undertaken. Specimens of the former were obtained from a large hollow cylindrical forging, an etched section of which
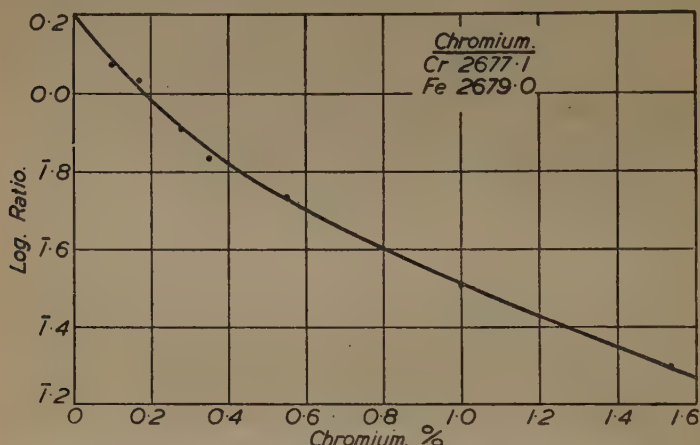
FIG. 12.—Graph for the Determination of Chromium from Spark Spectrograms.
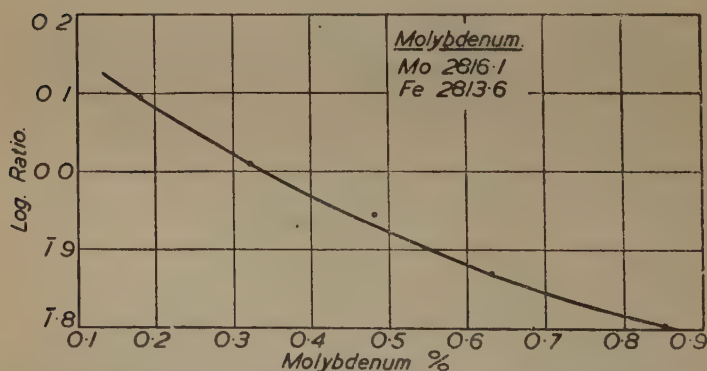
FIG. 13.—Graph for the Determination of Molybdenum from Spark Spectrograms.

is shown in Fig. 6. Most of the segregates were roughly circular in cross-section, having a diameter of approximately 0·04–0·08 in. Their length, however, was considerably greater, and on this account longitudinal sections were prepared for spectrographic examination. As the segregates were not visible on polished sections, an etch was

necessary to locate them. Of the various etching reagents in common use, previous experience had indicated that Oberhoffer's reagent was one of the most suitable, because the macrostructure and the segregates were readily revealed with the minimum of attack on the specimen.

TABLE I.—*Results of Tests on Nickel-Chromium-Molybdenum Steel* A.

Test No.	Silicon. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.
		Tests on Non-Segregate.			
1	0·15	0·49	2·77	0·65	0·43
2	0·17	0·46	2·68	0·59	0·42
3	0·18	0·50	2·68	0·59	0·44
4	0·17	0·46	2·55	0·55	0·39
5	0·17	0·47	2·75	0·62	0·44
6	0·18	0·46	2·68	0·59	0·43
7	0·17	0·45	2·60	0·56	0·38
8	0·16	0·49	2·65	0·56	0·39
9	0·17	0·47	2·73	0·61	0·42
10	0·17	0·46	2·68	0·58	0·40
Average	0·17	0·47	2·68	0·59	0·41
Greatest deviation } from average }	+0·01 −0·02	+0·03 −0·02	+0·09 −0·13	+0·06 −0·04	+0·03 −0·03
		Tests on Segregate.			
11	0·20	0·47	3·02	0·71	0·88
12	0·21	...	3·07	0·73	0·78
13	0·21	0·66	2·94	0·72	0·63
14	0·21	0·73	2·90	0·68	0·66
15	0·21	0·49	2·78	0·61	0·52
16	0·19	0·53	2·82	0·65	0·53
17	0·19	0·49	2·87	0·62	0·51
18	0·21	0·53	3·00	0 72	0·54
19	0·19	0·50	2·76	0·64	0·55
20	0·21	0·54	3·01	0·75	0·57
Average	0·20	0·55	2·92	0·68	0·62
Greatest deviation } from average }	+0·01 −0·01	+0·18 −0·08	+0·15 −0·16	+0·07 −0·07	+0·26 −0·11

After etching, a number of separate exposures were made on the segregate and on the normal metal in positions well removed from it. The macrostructure of the specimen, and the size of the craters formed during the exposure, relative to the width of the segregate, are shown in Fig. 7. The results of analysis are given in Table I.

Another specimen cut from a forging of similar composition which contained segregates of a similar type was also examined, with the results given in Table II. The results on the non-segregated parts of these specimens show greater variation than that

TABLE II.—*Results of Tests on Nickel-Chromium-Molybdenum Steel B.*

Test No.	Silicon. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.
Tests on Non-Segregate.					
1	...	0·44	2·58	0·67	0·42
2	0·16	0·45	2·62	0·65	0·39
3	0·17	0·50	2·55	0·59	0·40
4	0·17	0·49	2·63	0·66	0·44
5	0·18	0·47	2·65	0·63	0·47
6	0·19	0·49	2·62	0·60	0·44
7	0·17	0·47	2·61	0·60	0·39
8	0·16	0·44	2·55	0·59	0·39
9	0·16	0·49	2·61	0·58	0·38
10	0·16	0·48	2·70	0·66	0·44
Average	0·17	0·47	2·61	0·62	0·42
Greatest deviation } from average	+0·02 −0·01	+0·03 −0·03	+0·09 −0·06	+0·05 −0·04	+0·05 −0·04
Tests on Segregate.					
11	0·20	0·49	2·92	0·68	0·63
12	0·21	0·51	2·63	0·59	0·51
13	0·19	0·49	2·80	0·62	0·51
14	0·20	0·52	2·83	0·66	0·66
15	0·21	0·94	2·91	0·62	0·60
16	0·20	0·76	2·95	0·64	0·56
17	0·22	0·68	3·12	0·78	0·74
18	0·20	0·77	2·91	0·67	0·65
19	0·20	0·74	2·63	0·57	0·48
20	0·20	0·60	3·06	0·74	0·68
Average	0·20	0·65	2·86	0·66	0·60
Greatest deviation } from average	+0·01 −0·01	+0·29 −0·16	+0·26 −0·23	+0·12 −0·09	+0·14 −0·09

generally obtained under normal conditions of routine analysis. Such variation, however, is not surprising, having in view the smallness of the area affected by sparking and the coarseness of the macrostructure. Much greater variation is shown in the results obtained from the segregates. The greatest differences occur on the manganese and molybdenum contents, the former being accounted for by the large inclusions of manganese sulphide, which were found to be much more numerous in the segregates than in the normal metal. An examination of the average compositions of the normal metal and the average of the segregates shows higher values for the latter for all elements; the greatest increases, however, occur with manganese and molybdenum, particularly the latter, where it amounts to 50% and 45%, respectively, on the two forgings.

An example of segregates found in a nickel-vanadium steel forging is shown in Fig. 8. The results of tests made in a similar manner to those described above are given in Table III. Here

TABLE III.—*Results of Tests on Nickel-Vanadium Steel Forging.*

Test No.	Silicon. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.	Vanadium. %.
			Tests on Non-Segregate.			
1	0·29	0·76	2·47	0·15	0·19	0·14
2	0·23	0·73	2·63	0·14	0·10	0·06
3	0·24	0·65	2·49	0·13	0·10	0·07
4	0·24	0·62	2·50	0·14	0·12	0·07
5	0·25	0·63	2·62	0·15	0·11	0·11
Average	0·25	0·68	2·54	0·14	0·12*	0·09
Greatest deviation from average	+0·04 −0·02	+0·08 −0·06	+0·09 −0·07	+0·01 −0·01	+0·07* −0·02*	+0·05 −0·03
			Tests on Segregate.			
1	0·26	0·73	2·80	0·15	0·15	0·16
2	0·28	0·76	2·73	0·13	0·13	0·16
3	0·24	0·82	2·75	0·17	0·19	0·19
4	0·24	0·82	2·67	0·16	0·20	0·21
5	0·27	0·85	2·73	0·16	0·20	0·18
Average	0·26	0·80	2·74	0·15	0·17	0·18
Greatest deviation from average	+0·02 −0·02	+0·05 −0·07	+0·06 −0·07	+0·02 −0·02	+0·03 −0·04	+0·03 −0·02

* Approximately.

again, higher average values for all elements were obtained on the segregates, and the greatest increases are shown for manganese, molybdenum and vanadium.

The problem of assessing the accuracy of these results is made very difficult because it is not possible when testing a heterogeneous material such as steel, under conditions such as those described above, to determine to what extent variability in the results is due to actual variation in composition and to what extent it is due to experimental error in the technique employed. It has been shown that the weight of metal actually involved in making an analysis is approximately 0·000005 g., and, even though it were possible to isolate such an amount for chemical examination, it is quite beyond the scope of the most modern methods of micro-analysis to obtain quantitative results from such a quantity.

It appeared that the best that could be done with the materials available was to obtain further evidence of reproducibility on bars of small section in which heterogeneity was less evident than in large forgings. Cross-sections of 1⅛-in. and 1-in. dia. bars were therefore prepared by polishing and etching, and ten tests made on each. The results of these tests are given in Tables IV. and V.

These results are considered to indicate reproducibility of a satisfactory order, and tend to confirm that the very much wider

TABLE IV.—*Results of Tests on Nickel-Chromium-Molybdenum Steel Bar. Dia., $1\frac{5}{8}$ in.*

Test No.	Silicon. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.
1	0·17	0·50	3·16	0·76	0·44
2	0·18	0·52	3·09	0·77	0·42
3	0·17	0·58	3·07	0·78	0·43
4	0·17	0·55	3·15	0·77	0·44
5	0·17	0·55	3·05	0·74	0·44
6	0·18	0·52	3·16	0·71	0·43
7	0·19	0·56	3·07	0·74	0·41
8	0·19	0·56	3·05	0·72	0·42
9	0·19	0·55	3·06	0·78	0·42
10	0·18	0·55	3·08	0·77	0·42
Average	0·18	0·54	3·10	0·76	0·43
Greatest deviation ⎱ from average ⎰	+0·01 −0·01	+0·04 −0·04	+0·06 −0·05	+0·02 −0·05	+0·01 −0·02

TABLE V.—*Results of Tests on Nickel-Chromium-Molybdenum Steel Bar. Dia., 1 in.*

Test No.	Silicon. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.
1	0·18	0·65	2·66	0·68	0·49
2	0·20	0·65	2·66	0·67	0·47
3	0·20	0·64	2·66	0·64	0·51
4	0·21	0·67	2·65	0·65	0·50
5	0·22	0·64	2·55	0·68	0·55
6	0·21	0·65	2·65	0·64	0·50
7	0·21	0·66	2·66	0·67	0·55
8	0·21	0·64	2·57	0·67	0·51
9	0·21	0·68	2·66	0·63	0·57
10	0·21	0·69	2·59	0·70	0·55
Average	0·20	0·66	2·63	0·67	0·52
Greatest deviation ⎱ from average ⎰	+0·02 −0·02	+0·03 −0·02	+0·03 −0·08	+0·03 −0·04	+0·05 −0·05

differences experienced with forgings between the results on normal metal and those on segregates are due largely to differences in actual composition.

A number of the spectrograms obtained in the course of the tests reported above have been examined for carbon, but the results, even on the small bars, showed such variation as to make it doubtful whether the conditions of test employed are satisfactory for this element. No results have therefore been reported, and further work to determine the best conditions for the estimation of carbon is in hand.

It should be pointed out that, when making the tests on segregates, the actual points tested did not in many instances fall on

the axis of the segregates, and their positions relative to the axis were generally irregular. It is considered that the variation in composition which is indicated to exist within a single segregate is probably due to this cause, and an effort is now to be made to determine the graduation in composition from one side to the other. It is proposed to carry out tests under conditions in which the photographic plate and the specimen are slowly traversed during sparking, their movements being synchronised, so that a continuous spectrogram showing the graduation in composition across the segregate may be obtained. Much work, however, will have to be done to establish the best conditions for such a test, and this will form the subject of a future paper.

DISCUSSION.

(Fig. A = Plate XX.)

Mr. E. S. DREBLOW (Messrs. Adam Hilger, Ltd., London) remarked that the paper seemed to be a very promising piece of work on a new application of the spectrograph, and there was very little fault that he could find with it.   There was, however, one suggestion which he would like to make.   In dealing with the conditions provisionally adopted for the analysis of segregates, the authors gave the distance of the electrode from the slit as 4 in. The length of the slit was not given, but it happened to be $2\frac{1}{2}$ mm. A certain amount of light was lost in the spectrograph; probably it was of the order of 40%.   He would suggest, therefore, that a condensing lens should be placed between the light source and the slit; that should give a good deal more light.   It should also help from the point of view that some of the light which was scattered outside the lens might lead to inaccuracy, and, since with the lens the whole light would be contained within the optical system, different results might be obtained.

There was one point that he would like to put to the authors with regard to the final size of the electrode.   They made no statement as to how long the electrode lasted, and he thought that that was important from the point of view of how much the cross-sectional area of the electrode itself varied over a given time.

Dr. L. FROMMER (High Duty Alloys Ltd., Slough) began by saying how very interesting this paper was to everyone concerned with spectrographic analysis, since it seemed to offer a new approach to special problems.   He would like to mention that he had been tackling the question of the analysis of constituent segregations and of micro-inclusions in light alloys.   He had, however, approached the problem in a different way, viz., by bodily removing the very small particles in question, by means of scraping or some similar process, and subjecting them to spectrographic micro-analysis by means of a direct-current arc between spectrographically pure graphite electrodes in the following manner :

The specimen, which might have any weight between 0·3 and 10 mg., was placed inside the cavity of the lower electrode (the anode) the tip of which was a thin hollow cylinder, while the upper electrode (the cathode) was in the shape of a very thin pencil.   He found that success, as in the case of the authors' method, depended largely on the shape of the electrodes (suitable shapes having been found only after a good deal of experimental work) and on the use of an adequate current intensity.   Once he had succeeded in establishing satisfactory experimental conditions, it was possible to have the whole cored anode tip, with the specimen contained in its cavity, neatly consumed by the arc.   The exposure was taken during this whole

process so that the spectrum recorded on the photographic plate was representative of the total spectral energy emitted by the whole specimen during the process of being arced away.   Together with the spectra of the specimens to be analysed, a logarithmically stepped spectrum of an iron bead arc (as described by Pfundt) was recorded on the same- plate, enabling the characteristic H and D curve ($D - \log E$ curve) to be established.   Thus the spectra of the samples could be evaluated by correlation with standard spectra taken on other plates from similar samples of known composition, from which a " working curve " had been established (plotting the log ratio of the intensities of selected lines from the element sought and from the base metal against the log content of the element sought).

He had completed the working out of the experimental details only recently and had employed the method experimentally on a number of specimens.   The results were very satisfactory, the mean error of an individual determination being of the order of about 10%, which was a good accuracy in the case of such small specimens.   He felt that the method could also be applied with equal success to specimens of much smaller weight, even down to 0·01 mg., if proper means for handling such small quantities were available, which, at the time, he had not at his disposal.

In view of the satisfactory accuracy obtained he felt that this method of micro-analysis might prove suitable for the analysis of segregations, micro-inclusions and other inhomogeneities of light-alloy specimens.   He believed that in these applications an advantage could be seen in the certainty that, since the whole specimen was volatilised, every one of its constituents was forced to record its spectrum quantitatively, whereas this could not always be guaranteed in a method using a high-frequency spark acting on the surface of an integral sample, where the selective action of the high-frequency spark was to be reckoned with—an effect which was rather pronounced in the case of light alloy samples.   He mentioned one application of the new method which had just been completed at the time of speaking and which consisted in the following :

From two samples, of which one showed fine and the other coarse constituent distributions under the microscope, specimens were removed in the form of fine shavings, and ten weighings from each were subjected to the spectrographic micro-analysis.   The ten results obtained from the sample showing coarse constituent distribution exhibited, amongst themselves, much greater deviation than the ten results obtained from the other sample, the microscopic and the micro-spectrographic findings thus being fully in conformity with each other.   He thought that the method could perhaps be applied also to the investigation of segregates in steel, but he had not made any experiments in that direction, his work at present being entirely confined to light alloys.

Finally he would like to draw attention to a paper published a

few years ago by G. Scheibe and Z. Martin,[1] where a method of micro-analysis was described which was somewhat similar to that described in the present paper, though a rather different method of excitation was used.   It might be of interest to compare the relative merits of these two methods.

Mr. D. A. OLIVER (Messrs. Wm. Jessop & Sons, Ltd., Sheffield) welcomed the method described in the paper, and said that from an experimental point of view the work which the authors had done was of an exceptionally high order.   The beauty of the method, as he saw it, was that in attempting to find out more about these segregates it was only necessary to examine a polished section containing the segregate; it did not involve mechanical methods of chipping it out and then analysing it by some method such as that which had just been described by Dr. Frommer, or by other microchemical means.   The relative size of the sparking points in Figs. 7 and 8 was very convincing from the point of view that it was possible to get three or four determinations transversely to the segregate as well as a large number along its length.

The method was at the moment largely of research interest, but it did increase the degree of discrimination possible in studying segregation on a progressively smaller scale, and from that point of view it would show great superiority over glancing-angle X-ray determinations, which could not at the moment be done on the segregate without getting superimposed large-intensity reflections from the surrounding matrix.

Finally the authors were to be congratulated on the ingenuity of the technique employed to determine the effect of the spreading halo associated with the miniature spark.

Mr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) said that he thought the authors deserved praise for the patient way in which they had endeavoured to perfect an elegant method of examining segregates in steel.   Unfortunately, even now, the three elements most concerned in segregation, namely, carbon, phosphorus and sulphur, could not apparently be estimated by this method, so that there was still scope for much further work.   Of the elements which had so far been determined, manganese and molybdenum were found to segregate the most.   As the authors had stated, the relatively high manganese increment might be due to the presence of large MnS inclusions.   He thought that was probably correct and wished to suggest that part of the molybdenum increase might have occurred in the same manner, since there was some evidence to indicate that molybdenum also formed a sulphide.   For instance, it was well known that the

[1] G. Scheibe and Z. Martin, " A New Application of Emission Spectroscopy to Local Micro-analysis," *Spectrochimica Acta*, 1939, vol. 1, No. 1, p. 47.

whole of the sulphur in steels containing molybdenum was not liberated as sulphuretted hydrogen when drillings were dissolved in hydrochloric acid, for the results given by the evolution method were low. ·Yet when a plain carbon steel was dissolved in hydrochloric acid, to which an amount of molybdenum equivalent to 0·5% had first been added, the correct result could be obtained. Hence, it looked as though molybdenum was partly combined with sulphur in steel and the sulphide was not decomposed by hydrochloric acid. Again, in examining under the microscope steels in which about 0·5% of molybdenum was present, he had noticed that the sulphide particles were sometimes duplex in structure, one component having the characteristic colour of MnS, the other being much lighter, as shown in Fig. A. For these reasons he thought that segregates might possibly be enriched by the presence of molybdenum sulphide as well as manganese sulphide.

Mr. D. M. SMITH (British Non-Ferrous Metals Research Association, London) said he felt a little diffident about taking part in the discussion, as most of his work on the spectrographic analysis of steel belonged to what might be termed the " pre-microphotometer era." However, there were several points in the paper to which he would refer, and he would like also to digress a little and draw attention to the previous paper by Mr. Barker in 1939,[1] when Mr. Barker introduced a novel technique by using no added inductance in the spark circuit, together with a counter-electrode of graphite. Those who were working with non-ferrous metals and alloys naturally tried that technique for such alloys, and he had recently had the privilege of seeing the work of Mr. Edwards, of the Admiralty Laboratory at Birmingham University, where the method was being applied, with excellent results, to the analysis of aluminium and its alloys. Moreover, there was evidence that it was useful for many other analytical purposes.

Spectroscopists for a number of years had been asked to identify inclusions, stains and impurities in cracks, and so on, but more often than not the information obtained had been purely qualitative; it was often a question of identifying an element which was causing trouble. The present method put the analysis of segregates on a really quantitative basis.

In working out the results of spectrographic analysis one could not always rely entirely on check chemical analyses, but a great deal could be done by statistical methods, of which that of the authors was a type, and he would suggest that possibly the use of the standard deviation might give information as well. Nevertheless, the results given were convincing, and, turning to non-ferrous applications, he felt sure that it would be possible to apply the method to identifying the distribution of impurities in

[1] *Journal of the Iron and Steel Institute*, 1939, No. I., p. 211 P.

coarsely crystalline structures, for example, and no doubt numerous other applications would arise as time went on.

Another point which impressed him as having been well worth investigating was the influence of the halo on the analysis of the crater. The authors had established an important point, in that the analysis only referred to the material volatilised from the crater.

Mr. E. H. S. VAN SOMEREN (Broxbourne, Herts.) expressed appreciation of the paper and said he hoped to be in a position to take advantage of its results in a few months' time, so that he was very glad that the exploratory work had been done. He had tried some years ago in copper ingots to explore the segregation of some impurities, and had been led up to doing so by the fact that, when investigating copper and zinc specimens spectrographically, considerable differences were found in the impurities contained when examining a fractured surface or a machined surface. In the case of intercrystalline fracture, where there was segregation of impurities at the crystal boundaries, it showed up the way in which spectrographic analysis could be upset by segregation, as well as helping to detect that segregation when it occurred.

He was glad that Dr. Frommer had raised the question of the small high-frequency spark, because that work had been followed up in the United States of America by Murray, Gettys and Ashley,[1] who succeeded in making a spark source that was fed by an oscillating circuit which affected an area of the specimen only about one-quarter of the diameter of that with the spark used by the present authors; but he would like to ask the authors whether they agreed with the conclusion in that paper, which was that the smaller the spark, from the point of view of localisation, the less sensitive it was to impurities, and, therefore, if one tried to improve the spark so that one was analysing only the centre of the segregate, one might lose all the sensitiveness to impurities and defeat the accuracy of one's analysis.

He would also like to ask the authors whether they found it possible to assist in the localisation of the spark by some etching or staining process which produced selective oxidation of some one or other of the constituents in the specimen, because sometimes quite a thin oxide film over a portion of the specimen would help to localise the spark on another portion. He believed that that method was first used on aluminium alloys some years ago.

AUTHORS' REPLY.

The AUTHORS agreed with Mr. Dreblow that the use of a condensing lens between the light source and the slit would increase the

[1] *Journal of the Optical Society of America,* 1941, vol. 31, p. 438.

amount of available light that was subsequently recorded on the photographic plate. This increase in light intensity, however, had been found under the provisional conditions adopted for this investigation to be offset by a reduction in the image size as recorded on the plate. Further, the introduction of any additional optical part was obviously undesirable unless some very definite improvement was to be achieved.

Mr. Dreblow's suggestion that light which was scattered outside the lens might lead to inaccuracy was not borne out by the results of tests for reproducibility which were recorded in Tables IV. and V. of the paper. Further tests, which had since been made on well-worked bars in which there was little trace of ingotism, had given even more uniform results.

In reply to the further question of Mr. Dreblow as to the dimensional changes and life of the electrode under the conditions adopted for sparking, it had been found that during the pre-sparking period of 15 sec. the extreme tip of the point became slightly rounded. The rate of change in subsequent 15-sec. periods of sparking was very small, the total decrease in length after twelve such periods being only 0·15 mm. The effect of such an increase on the crater size was very small.

The authors thanked Dr. Frommer for the very interesting account of his work in a similar field to that covered by their own investigation. Although his work was confined chiefly to non-ferrous metals no reason was seen why the technique that he had developed should not also be applied to steel. The chief disadvantages of the method, however, over the one described by the authors were the necessity for the removal of a portion of the segregate by mechanical means from the metal in which it occurred, and the difficulty involved in weighing accurately such a small amount of material. Although the weighing of 3–10 mg., such as were used by Dr. Frommer, presented no difficulty, the weighing of 0·005 mg., which was the total weight of metal involved in making an analysis by the method described in the paper, could not be accomplished even with the finest micro-balance with the accuracy necessary for any quantitative analysis.

The crater formed by sparking was very uniform, and one could reasonably assume the complete volatilisation of the material in the zone under examination.

For the reasons stated, it was considered that the technique described by the authors was more suited to the examination of segregates, particularly when it was required to determine whether variations in composition occurred within the segregates themselves.

Dr. Frommer also drew attention to the work of Scheibe and Martin as published in *Spectrochimica Acta*, 1939. Their procedure involved a high-voltage spark discharge, which was generated and rectified by means of a valve system. The spark was very small and affected an area about one quarter of that affected with the

authors' method.   A disadvantage, however, associated with the employment of these conditions was that the electrical excitation thus required reduced the sensitivity of the method.

Scheibe and Martin made their tests in an inert atmosphere of low pressure, and the resulting spectrograms were obscured in several places by band spectra.   When a small spark was substituted for the slit of the spectrograph as in their method, the spectral lines recorded on the plate showed poor definition.   The general set-up of their apparatus was very complex when compared with that of the authors.   A very useful component, however, was the microscope for selecting and examining the area to be tested.

Mr. Oliver pointed out the difficulties attendant on the use of the method of segregate analysis described by Dr. Frommer.   This had already been commented upon in the authors' reply to Dr. Frommer.

The generous comments of Mr. Oliver on the paper were much appreciated.

The remarks of Mr. Whiteley with respect to the necessity for further work to cover the elements carbon, sulphur and phosphorus, which were commonly associated with segregation, were endorsed. Much work in this connection had already been done by the authors, and more was in progress.   These three elements, when present in steel, were found to be very difficult to excite adequately to permit of their determination spectrographically.   When the spark had bridged the gap between the upper electrode and the sample, the potential fell to a comparatively low value, and since the main current carriers were the ions of the metals which had a lower ionisation potential than carbon and sulphur, the emission from the latter elements fell after a very short period of sparking, thus rendering a spectral record very difficult to obtain.   The obstacles with regard to carbon, however, had been largely overcome, and the conditions under which it could be estimated quantitatively with a fair degree of accuracy would be included in a further paper, which was being prepared by the authors.

With regard to Mr. Whiteley's suggestion that the higher molybdenum content of the segregate might be due to the presence of molybdenum sulphide, whilst it was considered probable that a part of the excess molybdenum was present in this form, tests which had been made in zones where sulphide inclusions were few and small had indicated that some of the excess was combined with the metallic constituents of the segregate.   Further work was in hand to obtain more information on this point.

The authors thanked Mr. Smith for his kind observations on the paper.   They were in agreement with his view with respect to statistical methods, and employed them to determine the degree of accuracy of their work whenever it was practicable to do so.

With respect to Mr. Smith's comments on a previous paper by one of the authors, it was interesting to hear that the technique

described therein, in which no added inductance was employed in the spark circuit, had been found by him to be useful in other connections. The technique referred to was developed in the Bragg Laboratory about five years ago and had since been continuously employed for the analysis of a variety of alloys with very satisfactory results. It would be seen from the conditions of sparking given on p. 186 P of the present paper that no added inductance was employed in the technique which the authors had provisionally adopted for segregate analysis.

Mr. van Someren augmented Dr. Frommer's comments on the Scheibe method of using a small high-frequency spark by mentioning the study by Murray, Gettys and Ashley with respect to the properties of the Scheibe spark. In reply to his question with respect to the sensitivity of the Scheibe method, the authors agreed that there was some limit in regard to the size of the spark with respect to localisation which would permit of the quantitative determination of elements present in very small amounts. Concerning the authors' technique, it had been shown by the tests on alloy-steel bars described in the paper that the sensitivity obtained with their spark was such as permitted of the determination of the elements silicon, manganese, nickel, chromium and molybdenum with a high degree of accuracy.

In the Scheibe method it was not necessarily the size of the spark which limited the sensitivity, but the high potential of the discharge. This high potential produced the excitation of more highly ionised spectra, and it was known that as one receded from the arc conditions of excitation to the spark, and higher spark levels, the sensitivity diminished.

The localisation of the spark by etching or staining referred to by Mr. van Someren has not been attempted by the authors, but it would be borne in mind for future work.

A CO-OPERATIVE INVESTIGATION OF THE FACTORS INFLUENCING THE DURABILITY OF THE ROOFS OF BASIC OPEN-HEARTH FURNACES.*

A REPORT BY THE OPEN-HEARTH REFRACTORIES JOINT PANEL.†

(Figs. 21 to 47 = Plates XXI. to XXVIII.)

CONTENTS.

ABSTRACT.

The results of observational work on the roof of a basic open-hearth steel furnace are reported. The observations commenced

with the raw materials from which the silica roof was made, and ended with laboratory work on samples taken from the roof at the close of the campaign.   During the campaign itself a pyrometric record was made of the temperature at the surface and at various levels within the roof.

The raw quartzite contained a proportion of comparatively large grains which were more readily converted than the remainder of the rock; this was attributed to strain within the lattice.   The amount of tridymite produced in the fired product was to some extent dependent on the fineness of grinding.

On warming-up an open-hearth furnace care must be taken in controlling the pull of the stack; if the stack damper is suddenly opened before gassing, the temperature of the roof may fall 200–300° C. in a few minutes.   The readings of the radiation pyrometer focused on the roof in a large measure confirm the findings of American workers; in particular, temperature fluctuations of the order of 300° C. occurred during charging.   In addition to these violent changes in temperature, however, fluctuations of about 50° C. occurred at each reversal; these variations were substantiated by thermocouple readings.

The pyrometer record served to show that during the first two weeks of the campaign the temperature gradient near the hot face became greatly modified; this effect is assumed to be associated with the " seasoning " of the roof.   Other important factors bound up with seasoning may be the marked decrease in porosity and the slight increase in refractoriness of the cristobalite zone.   At a later stage in the campaign the roof became hotter at the tapping than at the charging side.

Sampling of the dust and slag carried by the waste gases confirmed that the furnace atmosphere is most dusty during charging; at this period the dust consists mainly of lime, but during melting iron oxide preponderates.

The zonal appearance of the used roof bricks was normal, but analysis showed that the iron oxide content of the cristobalite zone was a little higher than that of the tridymite zone, while the lime had concentrated nearer to the hot face than the pale-yellow zone usually assigned to it.   This zone was almost impermeable, owing to a narrow band of calcareous glass; its refractoriness was 1640° C. when powdered and rebonded.   Several samples had cracked laterally in the region of this glassy band.

The high temperature attained by the brickwork when a charge foams and the deleterious influence of foaming on the refractories have been confirmed.

The Report consists of a Foreword and six Sections, as indicated in the Contents above.

Foreword.

By T. SWINDEN, D.Met., Chairman, and A. T. GREEN, F.I.C., Secretary of the Open-Hearth Refractories Joint Panel.

The Open-Hearth Refractories Joint Panel was formed in 1937 to work under the ægis of both the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association.   The terms of reference were broadly defined as research into the properties of refractory materials and their behaviour when used in steel furnaces.

At the outset, the Chairman laid stress on the value of co-operative research by members of the Panel, but it was apparent that before such work could proceed effectively, the mass of data and experience already available must be carefully sifted.   The publication of the First Report on Refractory Materials * followed.   This Report made it clear that the most serious gaps in our understanding of the behaviour of refractories in service were in the sphere, not of the physics and chemistry of the refractories themselves, but of the definition of the conditions to which they are subjected in use. This was nowhere more evident than in the paucity of precise data on the conditions of atmosphere and temperature in the furnace itself; certain conflicting experiences of members of the Panel also emphasised the need for observational work.   Research of this character had already been carried out in America, and blast-furnaces, glass tanks and other installations have been examined in this manner in England.

As a result of discussion by the Panel it was decided that attention should first be directed to the roof, as being the most vulnerable part of the furnace, in that interim repairs are difficult; the life of the roof therefore controls the length of a campaign in no small measure.   The observational work envisaged would entail considerable expenditure of time and equipment, and in consequence it was felt that the investigation must be made as complete as possible. With this end in view it was decided, if practicable, to follow the manufacture of the roof in detail before commencing to record the furnace conditions and their effect.   At this stage the Oughtibridge Silica Firebrick Co., Ltd., kindly offered facilities for carrying out the first part of the work, and Mr. Percival Smith gave permission for the roof to be installed on a furnace at the Steel, Peech and Tozer branch of The United Steel Companies, Ltd.; this firm also undertook the installation of the pyrometer equipment.

The work thus initiated proceeded satisfactorily through the observational stage on the plant, and co-operation continued in the examination of samples selected from the roof at the close of the campaign; this section of the investigation was carried out at the Central Research Department and the Templeborough Laboratories of The United Steel Companies, Ltd., at the works laboratory of the Oughtibridge Silica Firebrick Co., Ltd., and at the Mellor Laboratories of the British Refractories Research Association.

It is hoped that this investigation has helped to establish certain of the factors which determine roof life and will serve as a guide to the direction in which further work may most profitably be undertaken.   If its more controversial points lead to additional research of a like nature being carried out elsewhere, the Report will have served a valuable purpose.

* *Iron and Steel Institute*, 1939, *Special Report No.* 26.

Section I.—The Manufacture of the Roof Bricks and their Properties before Use.

BY T. R. LYNAM, F.G.S., J. H. CHESTERS, PH.D., B.Sc., AND T. W. HOWIE, B.Sc.

(1) *Raw Materials.*

The principal raw materials employed were :

Bwlchgwyn quartzite	80%
Broken but unused silica brick	20%

The lime, sulphite lye and mineraliser were added in the form of a slurry, the lime addition being sufficient to raise the lime content of the fired brick to about 1·5%.

The quartzite and silica brick were passed through a jaw-crusher to a conveyor belt feeding the grinding mill. Samples taken from the conveyor belt showed that the quartzite varied in physical structure from the usual coarsely crystalline Welsh quartzite to a rather pebbly variety. Occasionally a pebble as large as 1 in. in dia. passed into the mill. Since it was thought that the various types might behave differently on firing, samples were taken for subsequent firing tests.

The results of microscopical and X-ray examination of the raw quartzite are given later.

(2) *Brick Manufacture.*

The jaw-crushed material, after dry-grinding in the mill, was transferred to a mixer in which the slurry addition was made. After about 20 min. mixing it was passed to the moulding tables for use.

(a) *Grading.*

Periodic batch samples were taken for grading. The first sample (marked *A*) had the following sieve analysis :

B.S. Sieves.					Batch *A*.	
+ 7-mesh	.	.	.	.	19%	⎫ 59·5%
7–25-mesh	.	.	.	.	40·5%	⎭
25–72-mesh	.	.	.	.	19·5%	
72–100-mesh	.	.	.	.	5·5%	⎫
100–150-mesh	.	.	.	.	4·0%	⎬ 21·0%
−150-mesh	.	.	.	.	11·5%	⎭

(b) *Moisture.*

Determinations using the calcium carbide rapid moisture tester gave the following values : Batch *A*, 6·6%; batch *B*, 7·2%.

(c) *Moulding.*

The bricks, mostly 12 in. by 6 in. by 3–2⅞ in., were made using pneumatic rammers. Special blocks of the above dimensions but

having a $\frac{1}{2}$-in. hole passing from the centre of the 6 in. by 3-in. face to within 0 in., $\frac{1}{2}$ in., 3 in., 6 in. and 9 in. of the 6 in. by $2\frac{7}{8}$-in. face, were also made for use with the thermocouple installation.

(d) *Drying.*

The bricks were dried in a tunnel dryer until their moisture content fell below 0·2%.

(e) *Firing.*

The dry bricks were set in a round down-draught-type kiln and given the normal firing treatment.

With a view to following the changes occurring in the quartzite grains during the firing of the bricks, rock of average " pebbliness " was crushed to the grain sizes given in Table I. and fired with the bricks in small silica crucibles. The grading of the " through 72

TABLE I.—*Grain Sizes and Densities of Quartzite Used in Conversion Tests.*

B.S. Sieve Section.				Grain-Size Range. Mm.	Specific Gravity after Firing.
$\frac{1}{2}$-in.–$\frac{1}{4}$-in.	.	.	.	12·7–6·3	2·378
$\frac{1}{4}$-in.–7-mesh	.	.	.	6·3–2·4	2·347
7–25-mesh	.	.	.	2·4–0·6	2·339
25–72-mesh	.	.	.	0·6–0·2	2·329
—72-mesh	.	.	.	<0·2	2·305

mesh section " was as follows : 72–100 mesh, 28%; 100–150 mesh, 22%; through 150 mesh, 50%. Lump samples of the normal Bwlchgwyn rock, pebbly rock and a large pebble about 1 in. in dia. were also included ; porosity determinations on these samples before and after firing gave the information set out in Table II. These results are very surprising, in that they suggest that the quartz pebble and the pebbly rock convert faster than the normal Bwlchgwyn rock.

TABLE II.—*Conversion Data on the Bwlchgwyn Quartzite.*

Material.				Porosity. %.	Bulk Density. G. per ml.	Specific Gravity (By Porosity).
Normal rock :						
Before firing	.	.	.	0·8	2·58	2·60
After firing	.	.	.	9·6	2·16	2·39
Pebbly rock :						
Before firing	.	.	.	1·2	2·59	2·62
After firing	.	.	.	12·4	2·05	2·34
Pebble :						
Before firing	.	.	.	0·4	2·64	2·65
After firing	.	.	.	9·0	2·14	2·36

The results of microscopical examination of thin sections cut through the samples before and after firing are summarised below :

Normal Quartzite.

(a) *Unfired.*—Fairly uniform crystal size of about 0·3–0·5 mm. Some "voids" filled with much smaller crystals. Slightly wavy extinction.

(b) *Fired.*—Only about 30–40% of raw quartz left. Cristobalite formed at the edge of the grains and along cracks.

Pebbly Quartzite.

(a) *Unfired.*—Large strained crystals several millimeters in diameter cemented together with more finely crystalline quartz and some quartz of the size found in the normal sample.

(b) *Fired.*—Pebbly material appears loose in the matrix. Conversion appears to have gone further than with normal material.

Pebble.

(a) *Unfired.*—Very large crystals several millimeters in diameter (or a large number of small crystals of slightly differing orientation).

(b) *Fired.*—Conversion similar to that obtained with normal sample, but crystals divided into smaller units by bands of cristobalite.

The results of the X-ray examination of the various samples are given in Section V.

(3) *Properties of the Unfired Bricks.*

The properties of the unfired bricks—samples from batches *A*, *B* and *C*—are summarised in Table III. It will be seen that the grading of the unfired brick (*A*) is only slightly finer than that of the brick batch, suggesting that very little crushing of the grains occurred during the ramming process. Other features of interest are the constancy of the grading, which is perhaps best considered

TABLE III.—*Properties of Unfired Silica Bricks.*

	Batch *A*.	Batch *B*.	Batch *C*.
Grading :			
+ 7-mesh B.S.	18 ⎱ 54%	20 ⎱ 56%	17 ⎱ 48%
7–25-mesh	36 ⎰	36 ⎰	31 ⎰
25–72-mesh	20%	17%	22%
72–150-mesh	12 ⎱ 26%	13 ⎱ 27%	15 ⎱ 30%
−150-mesh	14 ⎰	14 ⎰	15 ⎰
Bulk density (volumetric method).			
G. per ml.	2·08	2·05	2·05
Specific gravity (Rees-Hugill flask)	2·618	...	...
Permeability (perpendicular to 6 in. × 2⅞-in. face) :			
(*a*) Through one skin	0·0047	...	...
(*b*) No skin	0·0078	...	...

by grouping into coarse, medium and fine fractions, as has been done in the Table ; the specific gravity is low, owing to the incorporation in the batch of 20% of broken silica bricks. The permeability of the

unfired bricks was roughly only one-twentieth of that of the fired bricks; the skin effect in the unfired bricks can be attributed to the sulphite-lye addition.

(4) *Properties of the Fired Bricks.*

(a) *Chemical Analysis.*

Analyses of two bricks gave the results set out in Table IV.

TABLE IV.—*Chemical Composition of the Unused Bricks.*

	B.	*C.*
SiO_2. %	96·03	95·40
Al_2O_3. %	1·24	1·00
Fe_2O_3. %	0·79	0·90
TiO_2. %	0·16	Trace
CaO. %	1·17	1·55
MgO. %	0·03	0·08
Na_2O. %	0·10	...
K_2O. %	0·06	...
	99·58	98·93

(b) *Refractoriness.*

Tests carried out on three bricks gave results as follows : 1710° C., 1720° C., 1720° C.

(c) *Refractoriness-under-Load.*

Two rising-temperature tests were carried out, using a load of 50 lb. per sq. in.; in these the test-pieces failed by shear at 1680° C. and 1695° C., respectively.   A maintained-load test (25 lb. per sq. in.) at a constant temperature of 1600° C. resulted in an expansion of 0·25% in 1 hr.; in a second test at the same temperature but under double the load (50 lb. per sq. in.) a subsidence of 0·5% occurred. These figures are of interest in showing the suppression of the permanent expansion when the material is subjected to a high load, and suggest that little, if any, permanent expansion would occur in the roof loaded by its own weight.

(d) *Porosity, Bulk Density, Specific Gravity and Permeability.*

Tests were carried out on numerous samples to obtain information on the constancy of the manufacturing conditions; these results are set out in Table V.

It may be said that the porosity varied from 23 to 27%, the bulk density from 1·72 to 1·81 g. per ml., and the specific gravity from 2·31 to 2·36.   Six of the samples tested for porosity were also tested for permeability, with very constant results, as will be seen from Table V.   The permeability test is in general more sensitive to the

presence of making faults than is the porosity determination, and the small variation from 0·14 to 0·18 indicates a uniformly textured product.

TABLE V.—*Porosity, Density and Permeability Data on the Fired Bricks.*

Sample.				Apparent Porosity. %.	Bulk Density. G. per ml.	Specific Gravity.	Permeability.
$B1$.	.	.	.	25·1	1·74	2·31	...
$B2$.	.	.	.	26·2	1·71	...	...
$C1$.	.	.	.	23·4	1·76	2·34	0·153
$C2$.	.	.	.	22·7	1·81	2·35	...
$T1$.	.	.	.	25·1	1·74	2·32	0·161
$T2$.	.	.	.	24·5	1·77	2·31	0·180
$T3$.	.	.	.	26·9	1·73	2·32	0·165
$T4$.	.	.	.	25·2	1·74	2·31	0·135
$T5$.	.	.	.	26·8	1·72	2·32	0·138
$D2522$	.	.	.	25·3	1·75	2·34	...
$D2523$	.	.	.	25·7	1·75	2·35	...
$D2524$	.	.	.	24·8	1·77	2·36	...
$D2525$	.	.	.	27·3	1·70	2·35	...
$D2526$	.	.	.	24·2	1·77	2·33	...
Average .		.	.	25·2	1·75	2·33	0·155

(e) .*Cold Crushing Strength.*

A single test was carried out on a test-piece, 6 in. by 3 in. by 3 in., cut from one end of a roof block; the specimen was crushed on end and failed at 2520 lb. per sq. in. This may be considered an average figure for a silica product.

(f) *After-Expansion.*

The results of after-expansion tests (2 hr. at 1500° C.) are listed in Table VI. The specific-gravity results are also included as an indication of the degree of conversion, but the range in specific gravity is so small that no relationship can be expected between the two sets of figures; the after-expansion is low, however, and it is evident that the bricks were adequately fired.

TABLE VI.—*After-Expansion Data (2 hr. at 1500° C.).*

Sample No.				Specific Gravity.	Permanent Linear Expansion. %.
$T1$.	.	.	.	2·32	0·14
$T2$.	.	.	.	2·31	0·40
$T3$.	.	.	.	2·32	0·10
$T4$.	.	.	.	2·31	0·27
$T5$.	.	.	.	2·32	0·10

(g) *Reversible Expansion*.

Thermal-expansion curves for sample $T1$ up to 1000° C. are shown in Fig. 1; the brick selected for this test had porosity, bulk-density and specific-gravity values which coincided with the average for all the bricks examined. The rapid expansion in the inversion ranges of tridymite and cristobalite is evidence of high conversion, as also is the absence of any irregularity at 573° C., the inversion temperature of quartz. The two figures obtained for the total expansion from 20° to 1000° C. are a little higher than is usual for silica bricks.

(h) *Spalling Resistance*.

Tests [1] made on small prisms over a temperature interval up to 450° C. gave results varying from one to 5 cycles with an average of
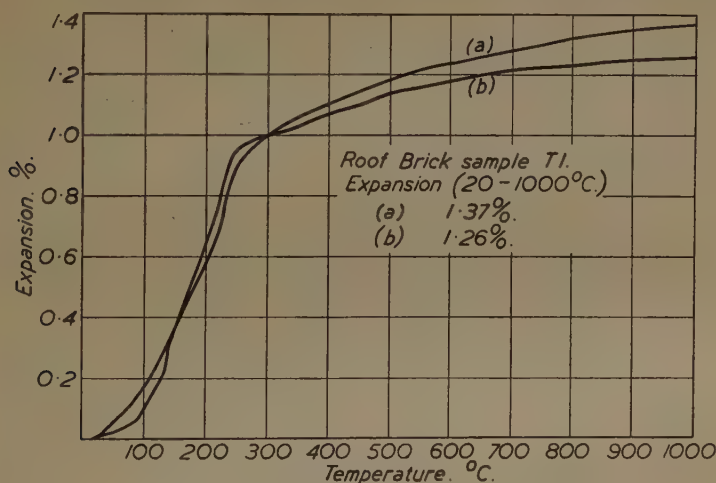
Fig. 1.—Thermal Expansion of Unused Bricks.

3 cycles. Spalling tests on silica bricks are difficult to render quantitative, but the test serves to emphasise the need for careful control in heating up the furnace.

(i) *Microstructure*.

Thin sections were cut from two of the bricks, and micro-examination gave the following results :

Sample B contained only a small proportion of unaltered quartz. The remainder was roughly half tridymite and half cristobalite.

Sample C contained about 15% of unconverted quartz and a smaller proportion of tridymite than B. The brick from which

this section was cut was not representative of the consignment; the sample was overlooked during the setting of the kiln and was inserted through the crown hole 24 hr. after the kiln was started.   Its position in the kiln led to incomplete conversion.

REFERENCE (Section I.).

(1) J. H. Chesters and L. Lee : *Transactions of the Ceramic Society*, 1937, vol. 36, p. 299.

Section II.—The Furnace and Pyrometer Installation.

By J. E. DOYLE, W. J. COLLINS and J. E. PLUCK.

The Furnace Construction.

The furnace selected for this work was an 80-ton fixed basic open-hearth furnace of normal construction.   The general lines and dimensions of the furnace are shown in Fig. 2.   The length between the blocks was 34 ft. 6 in. and the internal width was 14 ft. ; comparing these figures with those collected by the Open-Hearth Committee,[1] it will be found that this furnace was somewhat longer and wider than the average British furnace of similar capacity.   The area of the gas port was 2·6 sq. ft. and its inclination was 1 in 4. The single overhead air port was 10 ft. wide by 1 ft. 10 in. high (area $18\frac{1}{4}$ sq. ft.) ; the sole of the air port was inclined at 1 in 4 but the roof at 1 in 2.   These figures appear to conform to average British practice, as illustrated by the data of the Open-Hearth Committee.

The back and front walls were vertical and, with the exception of the silica door arches and upper jambs, were built of chrome-magnesite bricks.   The blocks were also faced with this type of refractory.   The upper portions of both the front and the back walls were rebuilt (14 in. thick) when the roof was put on, and this new work covered the skewbacks and one course of bricks on the inside.   The main roof reached from block to block and covered the full width of the furnace, *i.e.*, the roof was 34 ft. 6 in. long and 17 ft. wide.   At each end the ramp roofs lifted away for 6 ft. 9 in. at a slope of 1 in 2 ; the roof above the downtakes was flat and about 2 ft. 6 in. across.

The roof arch was built with a rise of $1\frac{1}{4}$ in. per foot span ; the steel skewback channels at the back and front of the furnace were at the same level.   The roof was not level from end to end, but had a rise of 17 in. from the ends to the middle ; the height of the middle of the crown above sill level was 6 ft. $9\frac{1}{2}$ in., while at the ends of the furnace the height was only 5 ft. $4\frac{1}{2}$ in.   The shape of brick used was an end-arch 12 in. by 6 in. by 3–$2\frac{7}{8}$ in. and the whole roof was built bonded, using 12 in. by 9 in. by 3–$2\frac{7}{8}$ in. end-arch alternately at the straight joint at each end (*see* Fig. 2).   The roof
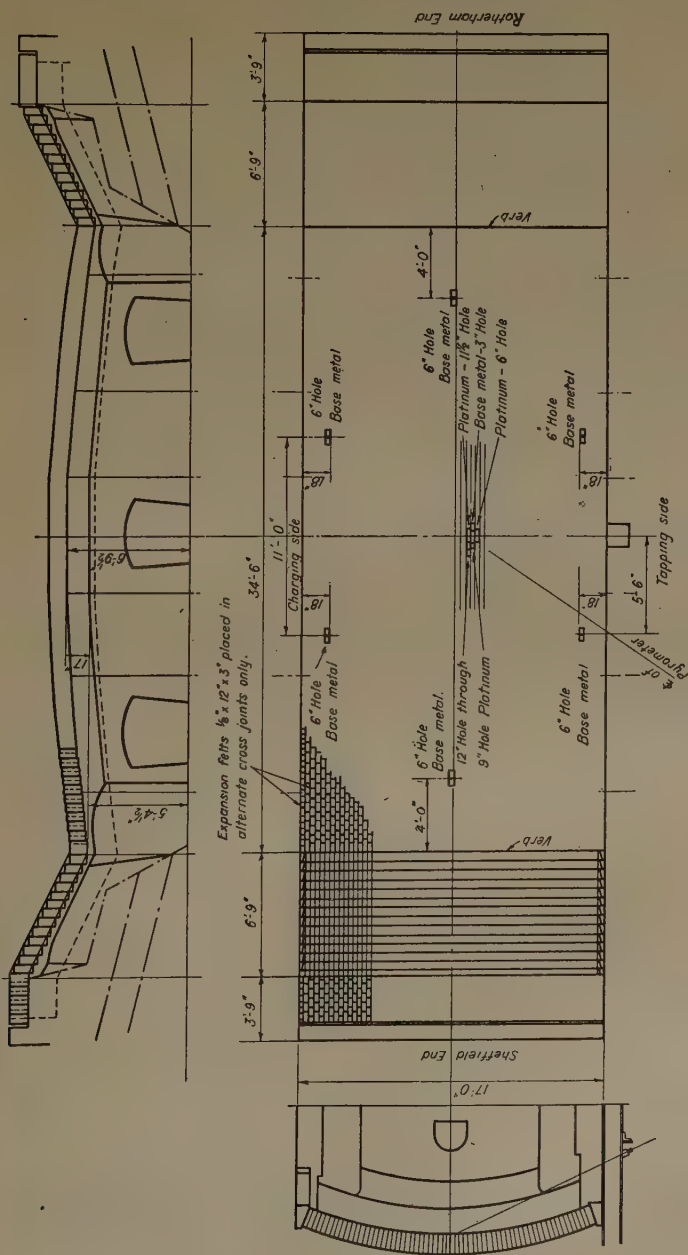
Fig. 2.—Plan of the Furnace.

was set dry except where it was necessary to correct the alignment for bonding the courses. No allowance was made for expansion across the arch, but longitudinal expansion was met by placing felts (12 in. by 3 in. by $\frac{1}{8}$-in.) in alternate cross joints.

Special blocks (made from the same batch of material as the remainder of the roof) having $\frac{1}{2}$-in. holes passing for various distances along their major axes were built into the roof to accommodate thermocouples. Their arrangement is described in Section III.
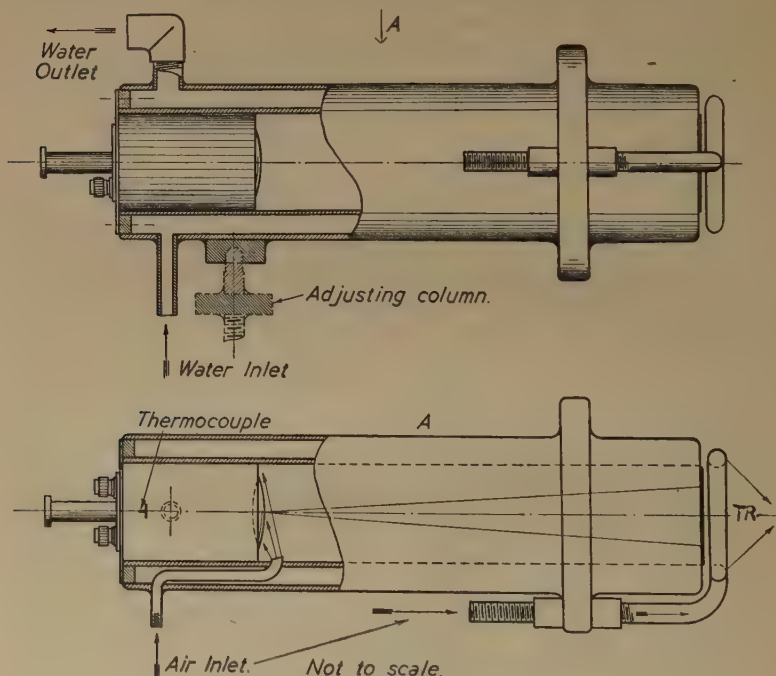
FIG. 3.—The Radiation Pyrometer.

Pyrometer Equipment.*

The pyrometric problem was to measure the temperature at various points on the surface of the furnace roof and inside the roof brickwork.

The temperature of the internal surface of the roof was determined by a water-jacketed lens-type receiving tube, *see* Fig. 3,

working in conjunction with a recorder based on the potentiometric principle and incorporating a galvanometer of high sensitivity. Provision was made for keeping the lens air-cooled, at the same time using the expelled air to prevent furnace flames and foreign bodies from clouding or damaging the lens. The steel water-jacket was approximately 24 in. long by $5\frac{1}{2}$ in. in outside diameter. Inside one end the receiving tube was fitted, and at the opposite end the carefully machined diaphragm, the aperture of which determined the calibration settings of the radiation unit.

The air supply, from a small fan, entered a short tube which passed through the water-jacket to the inside of the tube, where it streamed across the lens and then forced its way out past the diaphragm. After operating for a few weeks it was found necessary to fit a tuyere ring (TR) at the diaphragm or open end to assist in keeping the lens clean. The temperature of the cooling water was not allowed to exceed 40° C.

A steel platform attached to the structure at the back of the furnace was built to carry the complete radiation unit, while a special chrome-magnesite refractory block, with a conical sighting hole passing through it at a predetermined angle, ensured correct alignment on the target, which was an area roughly 5 ft. in dia. situated in the centre of the crown longitudinally but nearer the back wall than the front.

The recorder actuated by the radiation unit was mounted on the furnace stack a few feet above stage level, clear of the stage in order to lessen vibration. The range of the recorder was from 900° to 1800° C. and the scale width 10 in. Accuracy in recording and time-keeping was aimed at, and features of the recorder which made for reliability were automatic cold-junction compensation, automatic hourly current standardisation, potentiometric control, a continuous chart and an electrically driven clock. The lag between a change and the recording of temperature was 2·18 sec. The twin flex completing the circuit between the radiation unit and the recorder passed under the stage with other cables.

For the determination of the temperature gradient through the roof, ten special bricks were embodied in the furnace crown. Their positions are indicated in Fig. 4. Four of these bricks were located in the target area covered by the radiation unit. Each had a hole drilled partially through from the outside, the holes being respectively $11\frac{1}{2}$, 9, 6 and 3 in. deep. The roof was 12 in. thick, so that thermocouples inserted in the holes would give temperatures $\frac{1}{2}$, 3, 6 and 9 in. from the hot face of the crown. Two other bricks with holes 6 in. deep were placed 4 ft. from each end of the furnace on the centre-line of the roof.

Thermocouples, three platinum/platinum–13%-rhodium and three Hoskin's alloy (chromel-alumel) were inserted in these six holes and connected to a 6-point pyrometer for continuous recording. The four remaining special bricks were placed near the front

and back walls and were drilled with holes 6 in. deep. The temperature readings from these were taken at intervals with a portable indicator. The location simplified the use of a portable instrument during normal furnace working.

Where rare-metal couples were used, silica tubes were inserted in the bricks to give them an upright support. The Hoskin's wire, 14-gauge, was quite strong and was pushed rigidly into the bricks. Care was taken to see that all thermocouples were inserted to the full
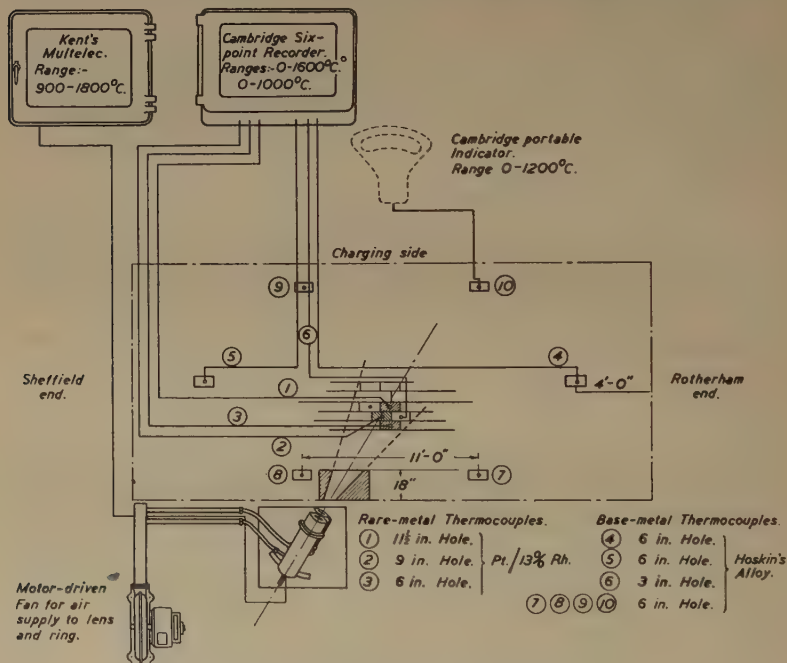
FIG. 4.—Complete Pyrometer Installation.

depth of the hole in each brick, and asbestos wool was pressed around the couples to seal the open ends of the holes.

The 6-point recorder employed was of the moving-coil type with double 24-hr. strip charts. One side was for platinum/platinum–13%-rhodium couples and the other for Hoskin's alloy.

Rubber-covered flex ran from the recorder to a junction box, placed at a convenient spot beneath the furnace stage, where the surrounding atmosphere was at a fairly constant temperature; this gave a reliable cold junction. The compensating leads from the junction box to the thermocouple heads were of nickel-copper.

The $11\frac{1}{2}$-in. thermocouple gave, during the three weeks that it

lasted, an excellent check on the temperature given by the roof recorder. Readings were also taken periodically with Wanner and disappearing-filament instruments to ensure accurate results from the radiation unit; a selection of the check readings is included in Table VII. Flame interference was very noticeable during charging periods, but this could not be avoided.

It was decided also to measure the temperature of the external surface of the roof, and this was done by means of contact thermo-couples used for spot readings only. These readings, in conjunction with the others taken at varying depths in the roof brickwork and on the internal surface, gave a representative temperature gradient through the whole crown.

Necessary attention to thermocouples was considered in preparing for the test, and a " cat-walk " of steel was built over the furnace, from which any of the equipment could be reached with a reasonable degree of comfort.

A general idea of the layout is given in Fig. 4.

TABLE VII.—*Calibration of Radiation Pyrometer.*

Date.	Disappearing-Filament Pyrometer.	Radiation Temperature Recorder.	Remarks.
	° C.	° C.	
13/11/39	1610	1585	
16/11/39	1620	1630	
22/11/39	1640	1650	
26/11/39	1600	1600	
29/11/39	1690	1700	
19/12/39	1660	1640	
22/12/39	1660	1670	
	1660	1680	
	1670	1680	
12/1/40	1720	1735	
22/1/40	1550	1540	Calibrated with middle doors half up at 7.20 P.M.
24/1/40	1525	1560	Gas taken off and readings taken after 2 min. Spar had just been fed after liming up.
25/1/40	1680	1700	
26/1/40	1440	1460	
26/1/40	1270	1280	Checked with gas off, recorder steady.

REFERENCE (Section II.).

(1) Symposium on Steelmaking, p. 373, *Iron and Steel Institute*, 1938, *Special Report No. 22.*

Section III.—The Furnace Campaign.

PART 1.—CONDITIONS OF SERVICE WITH PARTICULAR REFERENCE TO THE TEMPERATURE GRADIENT THROUGH THE ROOF.

BY A. E. DODD, M.Sc.(LOND.).

An important part of this investigation was a better definition of service conditions, and a full examination of the bricks after such defined service. With this end in view, a number of thermocouples were inserted into the roof, and a radiation pyrometer was focused on the centre of the roof through a hole in the back wall. The pyrometer installation is described in Section II.; some notes on the measurement and control of temperature in the open-hearth furnace have previously been given in the First Report on Refractory Materials.[1]

The Warming-Up Periods.

The furnace was warmed up by using gas flares through each of the three doors. The flares had individual controls, and were lit at 2.30 P.M. on November 5th, 1939; flares were lit in the slag pockets 36 hr. later. During the warming-up period the temperature was recorded at the hot face and at positions $\frac{1}{2}$ in., 3 in., 6 in. and 9 in. back. The temperature record is reproduced in Fig. 5. It will be seen that the temperature of the hot face increased steadily to 300° C. over a period of 48 hr.; the rate of heating was then somewhat accelerated and the exposed surface of the roof attained a temperature of 600° C. after about 65 hr. At this time the temperature gradient through the centre of the roof was as follows :

Position .	. Hot face	$\frac{1}{2}$ in. back	3 in. back	6 in. back	9 in. back
Temp. .	. 600° C.	580° C.	510° C.	400° C.	260° C.

Spot readings taken at different points on the roof, all 6 in. from the hot face, at this time (before gassing) gave the results set out below :

				East End.	Centre.	West End.
Charging side	.		.	306° C.	...	321° C.
Middle	.	.	.	...	400° C.	330° C.
Tapping side	.		.	285° C.	...	330° C.

During the preliminary warming-up the valve was set on centre, following the usual practice, and these temperature readings illustrate the cooling effect of the draught from the doors to the ports; the middle of the roof bricks at the centre of the furnace was roughly 100° C. hotter than the middle of the bricks at the ends of the roof.

Until a few minutes before the furnace was gassed, the stack damper had remained down. The effect of raising this damper just before gassing was remarkable; the temperature of the face of the

roof fell from 600° C. to 350° C. within about 10 min. (*see* Fig. 5).
From the accompanying temperature changes within the body of the
brickwork, it is clear that the pull of the stack after the damper was
raised was sufficient to draw air through the roof.   This inference
follows from the following figures :

Distance from hot face In.	.	.	0	$\frac{1}{2}$	3	6	9
Temp. drop on raising stack damper.							
°C.			250	80	10	10	40

The temperature dropped considerably more at a point near to the
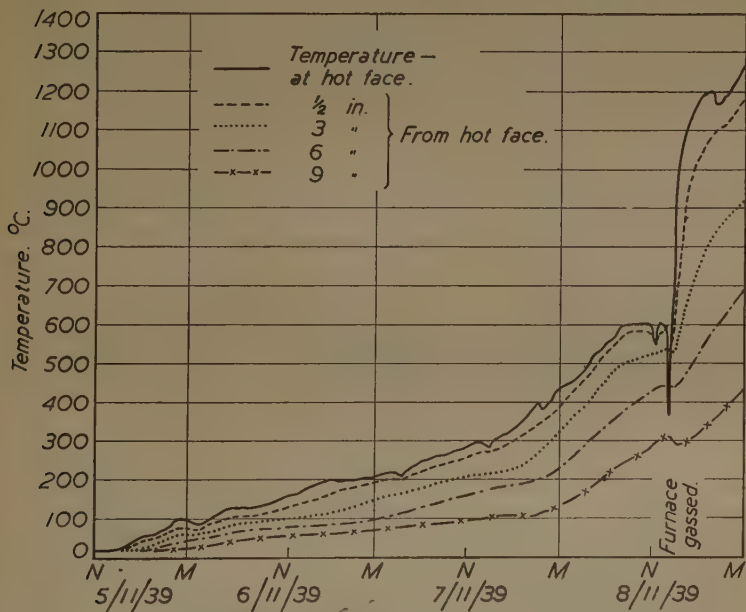
FIG. 5.—Temperature Record during Initial Warming-up.

outer face of the roof than in the middle of the brickwork;   this
could occur only if cold air from outside the furnace were drawn
through the roof.   The inner face would be cooled both by this
suction through the roof and, to a greater extent, by rapid cooling
of the interior of the furnace due to the cold air drawn through the
doors.

On gassing, the temperature of the inner surface of the roof rose
to 1000° C. within a few minutes;   the rate of heating then rapidly
decreased, and the roof reached 1400° C. some 12 hr. after gassing.
In spite of the chilling of the roof on raising the stack damper, the
surface temperature had not fallen into the range in which spalling

occurs as a result of the inversion of cristobalite; the temperature was considerably below the α–β quartz inversion point, however. This drop in the surface temperature would affect all quartz grains within about 1 in. of the hot face. A fall in temperature on opening the stack damper is difficult to avoid and has been observed at other plants; some modification in procedure should be made to overcome this chilling.

During the warming-up period the rise of the roof due to expan-
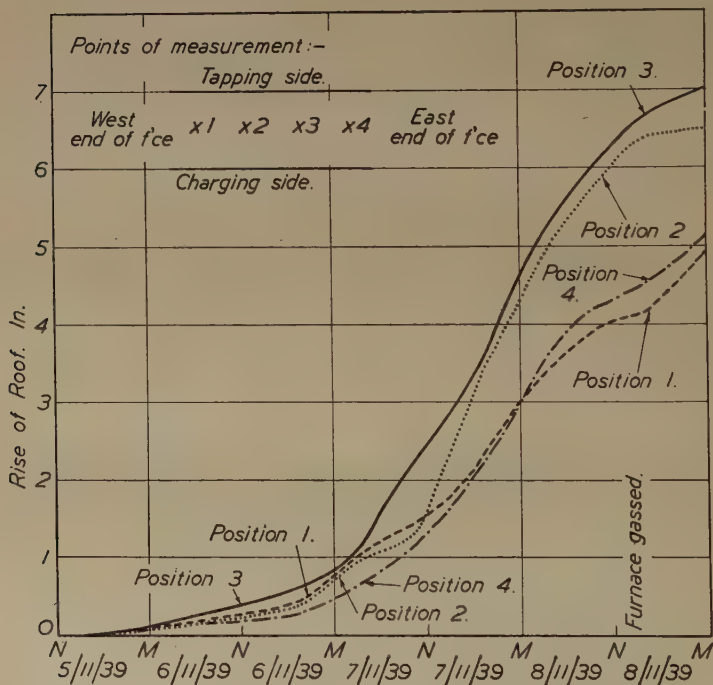
FIG. 6.—The Rise of the Roof during Warming-up.

sion was measured by noting the distance from the outer surface of the brickwork to the steel cross channels at four points along the top of the arch. The results of these measurements are shown in Fig. 6. During the heating-up period the rise at the ends of the roof was notably less than at the centre. This may be attributed to two factors : (a) The temperature at the ends was lower than in the middle of the furnace, as already noted, and (b) since the roof was of the " whale-back " type, it lifted longitudinally as well as across the arch. The first effect was nullified after gassing, for the ends of the roof continued to rise while the centre remained practically

stationary, but the longitudinal rise was still in evidence throughout the campaign.   The most significant feature of this record is brought out by comparing the temperatures of Fig. 5, with the measured rise of Fig. 6.   The temperature record refers to the middle of the roof, and it will be seen that the sudden increase in rise at the corresponding positions (2 and 3) occurred when the temperature was passing from 200° to 300° C.; this serves to emphasise that the most careful attention must be paid to the rate of rise of temperature in this range, for the expansion consequent on the α–β cristobalite inversion causes very large movements in the brickwork and such movements have to take place against compressive forces of a high order.

The temperature distribution in the roof bricks during a week-end shut-down has certain features of interest.   These will be described
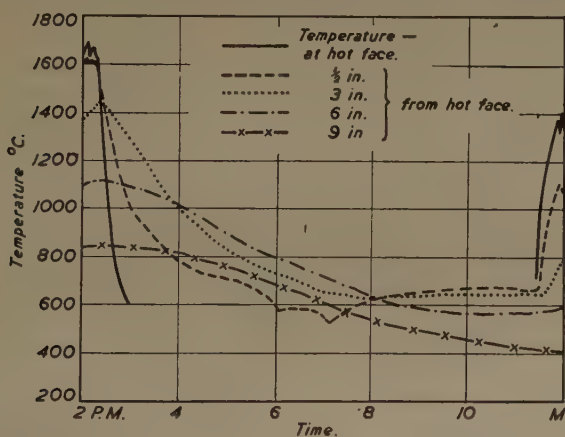
FIG. 7.—Temperatures within the Roof during a Week-End Shut-down.

for the second week-end of the campaign.   The gas was shut off at 2.20 P.M. on Saturday until 11.20 P.M. the same night.   The temperature at different points within the roof is shown in Fig. 7, and the general trend of these curves is typical for the whole of the campaign. The hot face chills very rapidly, and within a matter of minutes is colder than the centre of the brick; at a position close to the hot face ($\frac{1}{2}$ in. back) the temperature falls almost as rapidly.   About 3 hr. after the gas was taken out of the furnace the front 9 in. of the brick were at a comparatively uniform temperature (700–900° C.), the centre of the brick being the hottest.   A noteworthy feature of these temperature curves is the effect of closing the furnace doors after the completion of the week-end repair.   In this instance the doors were closed at 7.15 P.M., and the inner face of the roof immediately became hotter, although the back of the brick continued to cool off; this heating-up of the exposed face is due to radiation from the

lying-in charge, conduction from the interior of the brickwork and radiation from the furnace walls.

At the time of gassing on the Saturday night, the inner face of the roof was at a temperature of about 650° C., while 9 in. back the temperature had dropped to 400° C.   The almost instantaneous rise in temperature on gassing would be largely innocuous under these conditions, for no part of the roof (other than the outside face) had reached the temperature range of cristobalite inversion, and the inner half of the brickwork was above the temperature of quartz inversion.   After two weeks' working it is improbable that more than a trace of unaltered quartz was present at the hot end of the brick.   The fact that the temperature at the week-ends did not normally fall to the danger point is further indicated by measurements of the roof movement during these periods; this movement was less than 1 in. at the centre of the roof; and no more than $\frac{1}{2}$ in. towards the ends of the roof.

The heat stored in the furnace is sufficient to keep the temperature in the melting chamber above the critical spalling range for a very long period.   This was well illustrated during the Christmas shutdown.   The furnace was put off gas at 4 A.M. on December 23rd, and five days later the temperature gradient through the roof was as follows :

Inner surface .	.	.	.	.	.	. 315° C.
Approx. 2 in. from inner surface			.	.	.	325° C.
,, 5 ,, ,, ,,			.	.	.	280° C.
,, 8 ,, ,, ,,			.	.	.	220° C.

Shortly before gassing after this lengthy shut-down, the chimney damper was opened and the temperature of the inner surface of the roof rapidly fell to 180° C. ; on gassing, the surface temperature reached 1150° C. within an hour, but in spite of this severe treatment little spalling was noted.   The brickwork suffered still harsher treatment two weeks later, when the furnace was off gas for three days, owing to bottom trouble.   Within 3 hr. of tapping, the temperature of the inner face of the bricks had fallen to 600° C., and after 24 hr. the thermocouple at each level was recording some temperature below 200° C.   The temperature of the inner face ultimately reached that of the atmosphere, while the centre of the roof bricks was at 50° C.   Flares were put into the furnace, which was gassed after 6 hr. warming up; just before gassing, the temperature of the inner face of the roof was 350° C.   Even this treatment caused only a little visible spalling, but during the 6 hr. warming-up the roof lifted 7 in. and a crack opened along the top of the arch. The general contour of the roof was restored by packing up to the cross-ties.

Temperature Fluctuations within the Roof during a Single Melt.

The temperature fluctuations during a single cast have certain features which recur every heat; these will be considered as a pre-

liminary to discussing the slow alteration in the temperature gradient as the campaign progressed. A typical section of the temperature record is reproduced in Fig. 8. The furnace had been in operation for two weeks, and this was the twenty-fifth charge to be melted; the steel being made was of medium carbon (0·43–0·46%) content.

If the record is first examined from the general standpoint the following points may be noticed. On tapping, the hot-face temperature rapidly falls 300–400° C. This chilling affects the first $\frac{1}{2}$ in. of
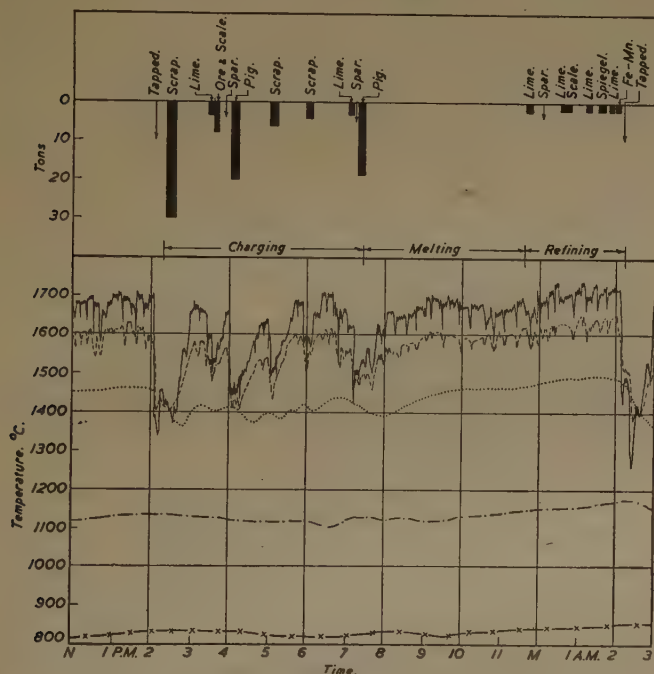
FIG. 8.—Temperature Fluctuations during a Heat.

the brickwork almost instantaneously, but 3 in. back there is a time lag of roughly $\frac{1}{2}$ hr.; at the centre of the brick this lag is of the order of 2 hr., while 9 in. back the maximum cooling effect following tapping is not attained until nearly 4 hr. later. During the charging period, sudden fluctuations of 200° C. are common, but later, during melting and refining, the temperature remains fairly steady. The large falls in temperature are easily accounted for, since they follow the charging process in a quantitative manner. Additions to the furnace during this heat are shown diagrammatically at the top of Fig. 8, and careful comparison of this part of the figure with the temperature record will show that all the major falls in temperature

have followed a charging operation. Minor fluctuations of about 50° C. also occur, however, but these are due to reversing the furnace. According to Sosman, [2] "readings taken in an open-hearth furnace while there is flame in the furnace give a false temperature, because of the reflection from the glazed roof and walls and from the liquid slag. The true temperature can be obtained only at the moment of reversal of the furnace. The short vertical lines extending downward from the main portion of the record would end in the true temperature of the roof if they could be made instantaneously, or if the temperature of the roof, slag and walls were uniform." This had appeared to be a sound conclusion, and at the beginning of this investigation it was accepted that momentary readings of 1700° C. and over were a result of flame reflection, the true maximum temperatures lying between 1650° and 1680° C. However, it was soon observed that the fluctuation of the radiation pyrometer at each reversal was accompanied by a corresponding fluctuation of the thermocouple nearest to the hot face. While the radiation pyrometer showed a fluctuation of about 50° C. at each reversal, the thermocouple initially $\frac{1}{2}$ in. back recorded a slower fall of about 20° C. This observation, repeated at each reversal until the thermocouple burnt out (after three weeks' working), is sufficient evidence that the fall of the radiation pyrometer on reversing is a record of an actual drop in the temperature of the hot face. The flame may interfere with the readings to a small extent, but since the thermocouple within the brick recorded a fall in temperature of 20° C. on reversing, it would appear improbable that the " flame error " of the radiation pyrometer was more than 10–20° C. These observations have led to the belief that the roof frequently attained a temperature of 1700° C. without visible damage, whereas Larsen and his co-workers [3] place the fusion temperature of a seasoned roof at 1650° C., a conclusion supported by Sosman on the basis of the SiO_2–FeO equilibrium diagram. Refractoriness tests carried out on the hottest zone of the roof bricks after use have helped to elucidate this problem, for while a test-piece *cut* from the nose of the brick did not soften until 1730° C., a cone made from the *powdered* material fused at 1690° C. It is evident that the equilibrium diagram can be used only as an indication of the nature of the nose of the brick at a particular temperature, for the brick is not homogeneous, consisting rather of a continuous skeleton of cristobalite and interstitial glass. If the cristobalite continuum remains undisturbed the softening temperature of the brick as a whole approaches that of pure cristobalite.

Returning to the larger temperature fluctuations which occur on charging, an analysis has been made of the extent of the drop for each type of material charged; these figures, obtained over a period of a week (twelve charges), are given in Table VIII. Referring to the continuous charging of several pans of one material as an " addition," it will be seen that the average temperature drop per

addition is greatest when charging pig, intermediate when charging scrap, and least when adding lime, scale or ore.   This order is considerably modified if the temperature drop per pan or per ton is

TABLE VIII.—*Roof Temperature Fluctuations due to Charging.*

Addition.	Average Number of Pans added at a Time.	Average Temp. °C.		Average Temp. Drop per Addition. °C.	Average Temp. Drop per Pan. °C.	Average Weight per Pan. Tons.	Average Temp. Drop per Ton. °C.
		Before Charging.	After Charging.				
Pig . . .	7·4	1584	1415	169	23	2·0	12
Scrap :							
(a) Heavy .	6·9	1534	1434	100	14	0·4	35
(b) Light .	12·4	1563	1454	109	9	0·25	36
Lime . .	3·3	1666	1610	56	17	0·65	26
Scale and ore .	2·9	1626	1583	43	15	1·5	10

calculated.   The drop per pan is least for light scrap, as would be anticipated, but the drop per ton is the same for light and heavy scrap.   It is particularly interesting to find that the fall in roof temperature per ton of pig charged is the same as the fall per ton of scale and ore, and, further, that these items of the charge and feed have the least effect on the furnace temperature if considered on a weight basis.   It would appear probable that the severe temperature fluctuations during charging, which must reduce the rate of output in addition to introducing stresses in the furnace structure, could be somewhat levelled out by adjusting the sequence and spacing of the charging operation; the effect of such modifications on the general working of the charge is not known.

Observations during the tenth week showed several features absent in the earlier stages of the campaign.   Fig. 9 shows the temperature at the surface of the roof during part of the 103rd heat, a medium-carbon charge.   The first new feature is that the furnace had by this time become a little out of balance, the roof temperature being 20–30° C. higher when the gas was entering from the east end of the furnace.   At 7.35 P.M. the gas was taken off for a few minutes and the radiation pyrometer was checked against a disappearing-filament pyrometer.   Three-quarters of an hour later the bath began to foam rather badly, and this sent the roof temperature up to 1760° C.; the foaming did not continue for very long, and this extremely high temperature was recorded for only a few minutes, but the roof was definitely damaged by this treatment. This offers a particularly good illustration of the effect of a foaming slag on the temperature conditions.

An attempt has been made to correlate the roof temperature with the type of steel being made, but this has met with little success. Classifying the charges according to their carbon contents, the average figures for the whole campaign are given in Table IX., but

the order of temperature for the four types of steel varies at different points within the brickwork; this is attributed to the time lag when a temperature wave passes backwards from the hot face.
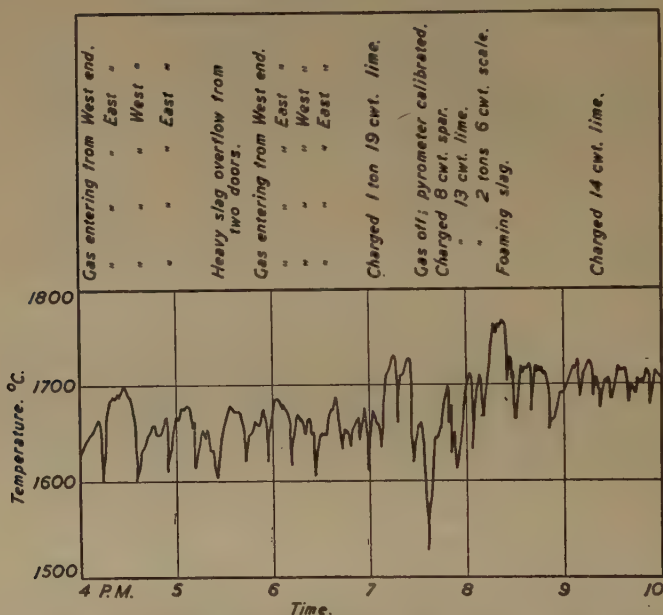
FIG. 9.—Temperature Fluctuations at a Later Stage of the Campaign.

TABLE IX.—*Average Roof Temperatures on Tapping for Different Classes of Steel.*

Carbon Content of Steel. %.	Peak Temp. ° C.	Temperature when Tapping. ° C.				
		Hot face.	¼ in. back.	3 in. back.	6 in. back.	9 in. back.
0–0·15	1720	1700	1630	1480	1165	835
0·15–0·30	1710	1680	1620	1470	1170	830
0·30–0·45	1730	1700	1620	1475	1170	840
0·45–0·60	1720	1685	1615	1465	1160	830

Change in Temperature Gradient During the Campaign.

The average temperature at the various points within the roof when tapping have been averaged over weekly periods; these data are set out in Table X.   From the fifth week onwards there was some doubt about the accuracy of the radiation pyrometer; corrections have been made on the basis of optical-pyrometer measurements,

and the probable hot-face temperatures are italicised in the Table.
The thermocouple originally $\frac{1}{2}$ in. from the working face was burned
out after three weeks' use. The general trend of these temperatures
is better visualised from Fig. 10. During the 19 weeks' run, the
temperature 9 in. from the outer surface increased by 130° C., but
the temperature at the centre of the brick rose 265° C.; the tem-
perature 3 in. from the outer surface increased only 145° C. This
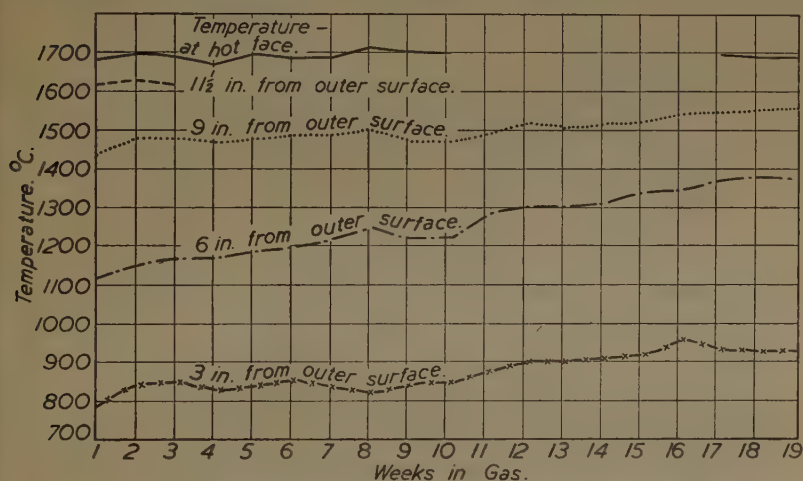
FIG. 10.—Temperatures within the Roof throughout the Campaign.

TABLE X.—*Weekly Average Tapping Temperatures.*

Week No. :	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Charge Nos. :	1– 11.	12– 23.	24– 35.	36– 46.	47– 58.	59– 69.	70– 78.	79– 89.	90– 94.	95– 105.
Peak temperature	1710	1725	1720	1690	*1725*	*1720*	*1720*	*1730*	*1730*	*1760*
Hot face, tapping	1680	1695	1690	1670	*1695*	*1690*	*1690*	*1710*	*1710*	*1700*
11¼ in. from outer surface	1615	1625	1620	...	...	...	...	...	...	...
9 in. from outer surface	1435	1480	1480	1470	1480	1485	1490	1500	1470	1470
6 ,, ,, ,,	1120	1150	1170	1170	1185	1200	1220	1250	1220	1220
3 ,, ,, ,,	785	840	850	830	835	855	840	820	840	850

Week No. :	11.	12.	13.	14.	15.	16.	17.	18.	19.	
Charge Nos. :	106– 113.	114– 121.	122– 131.	132– 143.	144– 154.	155– 166.	167– 178.	179– 189.	190– 200.	
Peak temperature	...	...	...	...	...	...	*1730*	*1700*	*1720*	
Hot face, tapping	...	...	...	...	...	...	*1695*	*1690*	*1690*	
11¼ in. from outer surface	...	...	...	...	...	...	...	...	...	
9 in. from outer surface	1490	1520	1510	1520	1525	1545	1550	1565	1565	
6 ,, ,, ,,	1290	1300	1300	1310	1335	1345	1370	1390	1385	
3 ,, ,, ,,	875	900	905	910	925	960	940	930	930	

variation is significant and shows that the zone rich in fluxes may attain a temperature at which the matrix will become relatively fluid.

The temperature gradient (at the tapping period) through the roof at the centre of the furnace at different stages in the campaign is shown in Fig. 11.   The first point arising from these curves is the pronounced change in the temperature gradient during the first two weeks' working ; the most significant feature of this change is the
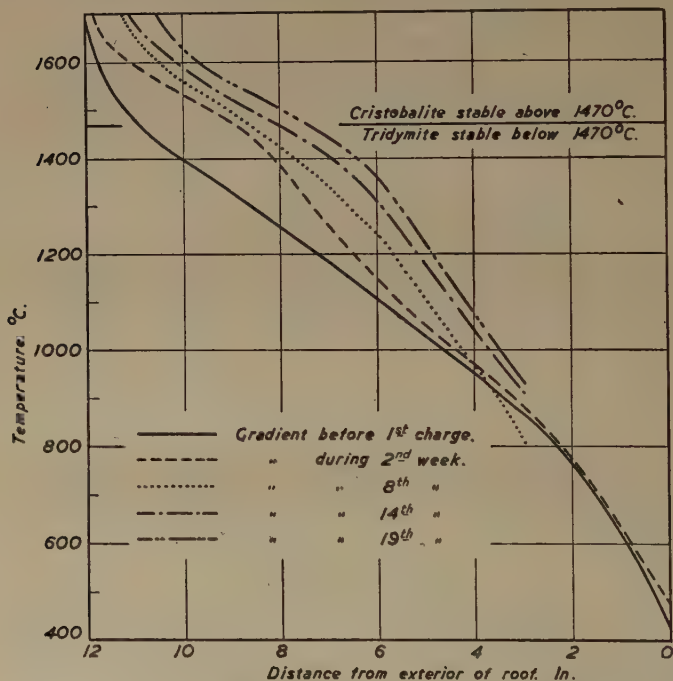
FIG. 11.—Temperature Gradient through the Roof at Different Stages in the Campaign.

increased conductivity of the zone a short distance behind the working face.   This, evidently, is associated with the well-known " seasoning " phenomenon, and suggests that one important effect of this seasoning is to eliminate the sudden drop in temperature at the hot face of a new roof.   A second feature which emerges from the gradients shown in Fig. 11 is the change in the slope of the curve at 1470° C., i.e., at the boundary of the grey cristobalite zone and the black tridymite zone.   The curves indicate that when once the roof is seasoned the grey zone has a higher over-all conductivity than

the contiguous black zone; this alteration in conductivity during use might be due to any or all of the following factors:

(a) Changes in texture.
(b) Changes in composition.
(c) Changes in the form of silica present.

Dealing with these in the order given, the mean porosity results obtained on twelve test-pieces cut from four bricks were 10·6% for the grey zone and 9·7% for the black zone. This difference is of the same order as previously published figures, but is insufficient to exert any marked effect on the conductivity. From the standpoint of composition, the grey and black zones vary mainly in their silica and iron oxide contents; the mean figures are given below:

	SiO_2.	Iron Calculated as Fe_2O_3.
Zone 1	85·8%	8·6%
,, 2	88·6%	6·1%

The results do not follow the generally accepted view that the iron-oxide content of the black zone is greater than that of the grey zone; these figures represent the average of three independent analyses. The thermal conductivity of a silica brick which has been slagged by iron oxide does not follow a simple additive law as is sometimes assumed. Eucken [4] has calculated the conductivity of a hypothetical silica brick of zero porosity containing different amounts of glassy material; this work led him to conclude that if the glass content is small the thermal conductivity has a negative temperature coefficient, but that when a considerable amount (50%) of glass is present the temperature coefficient becomes positive. Analytical and microscopical data suggest that at high temperatures the grey zone will contain more glassy (or liquid) material than the succeeding zone, but Eucken's work suggests that the actual difference in the quantity of glass present will not greatly affect the numerical value of the conductivity at high temperatures. Pierce and Austin [5] have shown that at temperatures above about 1400° C. the conductivity of the slagged brick may be appreciably less than that of the unused brick. Neither Eucken's nor Pierce and Austin's work affords a definite reason for the higher conductivity of the grey zone, however.

Turning to the third possibility, viz., a change in conductivity consequent on changes in the form of silica present, it has already been noted that the change in slope of the temperature curve occurs very close to the 1470° C. isothermal through the roof; hence it would appear that the tridymite at a temperature below 1470° C. has a lower conductivity than the cristobalite at a temperature above 1470° C. Conductivity measurements on actual crystals or pure aggregates of tridymite and cristobalite have not been made, but conclusions have been drawn from tests on silica bricks in which one or the other form of silica predominated. Thus Green [6] obtained figures which suggested that silica bricks rich in cristobalite had a

higher conductivity, but Kanz[7] arrived at an opposite conclusion. It is here suggested that the crystal size, shape and orientation may influence the thermal conductivity to give the gradient curves of Fig. 11.   The cristobalite crystals of the grey zone are granular and separated by films of ferruginous glass or liquid ; the tridymite crystals are much larger than the cristobalite crystals and are orientated with their long axes parallel to the direction of heat flow, and the ferruginous ground-mass is in consequence similarly orientated.   This feature may give rise to the change in direction of the temperature gradient at the junction of the two zones.

Temperature Difference within the Roof Between the Tapping and Charging Sides of the Furnace.

The base-metal thermocouples embedded 6 in. within the brick-work at two points towards the back skewback and at two points near the front skewback (see Fig. 4) gave a good comparison of the temperature of the roof at the back and at the front of the furnace. These thermocouples were not connected to a recorder, but spot readings were taken at intervals during the first twelve weeks ; after this time it was considered dangerous to be on the roof of the furnace while it was in operation.

The spot readings have been averaged over monthly periods in Table XI., and the corresponding average readings of the thermo-couple 6 in. in the roof at the centre of the furnace are included for comparison.   These figures show that during the first weeks of the campaign the temperature of the roof was practically the same at the pit side as at the charging side ; the roof appears to have been distinctly hotter in the centre during this period.   During December

TABLE XI.—*Average Temperature 6 In. from the Outer Surface of the Roof.*

	Centre.	Rotherham End.		Sheffield End.	
		Pit.	Stage.	Pit.	Stage.
	° C.	° C.	° C.	° C.	° C.
Nov., 1939 . .	1088	1018	1017	1027	1015
Dec., 1939 . .	1175	1081	1071	1080	1053
Jan., 1940 . .	1140	1202	1022	1156	1135

the temperature within the roof at the pit side became higher than at corresponding points at the charging side, but the centre of the roof remained the hottest area.   In January, the difference of 20–30° C. persisted at the Sheffield end of the furnace, but the roof at the pit side at the Rotherham end became very much hotter, indicating a period of rapid wear.   This aggravated erosion cannot have been due merely to hotter working, for the centre of the roof was on the aver-

age cooler than during December; the cause was more probably wear of the gas port at one end followed by mal-direction of the flame. It is significant that repairs to the blocks were carried out at this time. The appearance of the roof at this stage is shown in Fig. 21; it will be observed that there was a general roughening of the roof along the whole of the pit side, the extent of the wear being most marked above the tap-hole. The appearance of the roof at the end of the campaign is described in Part 4 of this Section.

PART 2.—THE NATURE OF THE DUST IN THE ATMOSPHERE IN A BASIC OPEN-HEARTH FURNACE.

BY J. H. CHESTERS, Ph.D., B.Sc., AND W. HUGILL, M.MET., F.R.M.S., A.R.P.S.

A number of attempts were made during the campaign to obtain information on the nature of the dust in the furnace atmosphere. The methods adopted were (a) filtering the furnace gases aspirated from the downtakes over a period of days, and (b) the deposition of dust on a platinum-lined refractory spoon. Dust samples taken from the flues and checkers were also examined.

A.—Sampling by Aspiration.

A sample was collected by drawing waste gases through a wash-bottle for three days during the seventh week of the campaign.

The liquid contained some very finely divided matter in suspension; there was also a thin film adhering to the inside of the flask above the level of the liquid. A few pieces of black material about 2 mm. in dia. were floating on the liquid. These were found on examination to consist of black slag and to contain many gas bubbles. These grains were attracted by a magnet. The liquid was decanted from the residue and the latter transferred to a clock-glass and dried. Examination under the microscope revealed the following (see also Fig. 22):

(1) *Material above 0·1 mm. in dia.*

(a) Black grains of similar character to those which floated, but of a solid type. These ranged from 0·5 to 0·1 mm. in dia. and were attracted by a magnet.

(b) Flat or slightly curved pieces of scale up to 3 mm. in dia. These were readily attracted by a magnet.

(c) At least one piece of turning. This consisted of one or two curls, with the turning marks clearly visible under the microscope, and had a metallic lustre with a slight patina.

(d) Several large fragments of colourless glass. These were splinters and showed characteristic striations. Size 3–4 mm.

(e) Numerous globules of slag ranging from 0·5 to 0·1 mm. in dia. Also a few irregular pieces of slag about 2 mm. in dia.

(f) Many fragments of silica brick 1 mm. in dia. and less.

(g) Rounded sand grains, about 0·75 mm. in dia.   There was no sign of cracking in these grains.

(2) *Material less than* 0·1 *mm. in dia.*
    (a) A large proportion of iron oxide, as scale, similar in character to (1b), but of sizes ranging to dust.
    (b) Slag as globules and as grains, the latter mainly as dust.
    (c) Crystalline fragments of mineral with parallel growth of low-to-medium double refraction, also a few single crystals of similar character. These were too small to be picked out for identification.

Chemical Analysis.

When this dust had been examined under the microscope, the entire sample was ground for analysis.   The results given in Table XII. were obtained;   MnO, Cr_2O_3 and P_2O_5 were sought but not found.   The total weight of the ignited sample was 0·0159 g.

TABLE XII.—*Analysis of Dust Aspirated from the Downtakes.*

	As Sampled.	Excluding Loss-on-Ignition.
SiO_2. %	21·9	36·5
Al_2O_3. %	17·0	28·3
Fe_2O_3. %	17·0	28·3
TiO_2. %	2·3	3·8
CaO. %	0·4	0·6
MgO. %	1·5	2·6
Loss on ignition. %	39·5	...
	99·6%	100·0%

B.—Sampling by Deposition on Platinum.

Samples were collected at different stages of a heat in a small spoon-shaped piece of platinum foil supported in a sectioned refractory tube; this " spoon " was inserted into the air downtake above stage level.   The samples were as follows :

    (i) 2·1078 g. of dust deposited in 10 min. during the charging of 5 pans of limestone, 1 pan of scale, 1 pan of ore and 1 pan of spar; the weight of metal in the bath at this stage was about 20 tons.   Size of platinum $1\frac{3}{4}$ in. by $1\frac{1}{2}$ in.
    (ii) 0·3404 g. of dust collected in 10 min. half an hour after the completion of charging.   Size of platinum $1\frac{3}{4}$ in. by $1\frac{1}{2}$ in.
    (iii) 0·7012 g. of dust deposited in 5 min. during the refining period.   The bath was boiling violently after a feed of ore. Size of platinum $2\frac{1}{4}$ in. by 2 in.

The compositions of these samples and their approximate rates of deposition are given in Table XIII.; copper, zinc and antimony were sought but not found.

TABLE XIII.—*Dust Samples Collected on Platinum Foil in Downtakes.*

	(i) Charging.	(ii) Melting.	(iii) Refining.
Dust collected per sq. ft. per hr. Lb..	1·5	0·3	0·6
SiO_2. %	Nil	7·06	10·14
Al_2O_3. %	4·68	7·40	11·89
Fe_3O_4. %	15·85	55·38	23·63
CaO. %	55·15	18·68	45·14
MgO. %	10·94	5·30	5·19
MnO. %	0·30	2·18	1·76
SnO_2. %	Nil	0·30	0·61
PbO_2. %	0·16	0·23	0·14
	87·08%	96·53%	98·50%

C.—*Sample of Dust from Furnace Culverts.*

A partial analysis was made of the dust deposited on the inspection lid of one of the air flues; the non-ferrous metals were sought with the following results :

SnO_2. %.	PbO_2. %.	ZnO. %.	CuO. %.
0·09	19·79	3·40	Nil

These figures may be compared with the following analyses of samples of dust deposited on the man-hole lids of the air flues of other basic furnaces at this plant :

Furnace	B	F	G	L	M	N
SnO_2. %	0·13	0·06	0·09	0·07	0·09	0·09
PbO_2. %	29·49	25·47	19·87	21·68	18·66	19·79
ZnO. %	4·86	7·30	4·95	2·48	2·64	3·40
CuO. %	Trace	Nil	Nil	Nil	Nil	Nil

D.—*Sample of Dust from Air Line.*

A $\frac{1}{2}$-in. dia. silica tube was inserted in the air flue and allowed to collect dust for 24 hr.; about 2 g. were collected and gave the following analysis :

SiO_2	3·38%	MgO	0·98%
Al_2O_3	2·74%	PbO_2	18·82%
FeO	0·64%	ZnO	2·80%
Fe_2O_3	32·01%	SO_3	23·22%
CaO	7·92%	Total	92·51%

E.—*Slagged Surface of Checker Bricks.*

At the conclusion of the campaign samples of bricks were taken from the checkers and the slagged surface was chipped off and analysed. The data obtained are included in Table XIV.

TABLE XIV.—*Analyses of Slagged Surface of Checker Bricks (Air Chamber).*

				Sheffield End. Tenth Course Down.	Rotherham End. First Course Down.	Typical Analysis of Bricks Before Use.
SiO_2.	%	.	.	11·10	23·23	55·0
Al_2O_3.	%	.	.	7·58	18·26	40·2
FeO.	%	.	.	46·29	38·83	...
Fe_2O_3.	%	.	.	...	...	3·2
CaO.	%	.	.	11·60	10·10	0·5
MgO.	%	.	.	2·70	2·92	0·7
MnO.	%	.	.	3·01	1·78	...
SnO_2.	%	.	.	0·05	0·06	...
PbO_2.	%	.	.	0·01	0·01	...
ZnO.	%	.	.	12·80	Nil	...
CuO.	%	.	.	Nil	Nil	...
				95·14%	95·19%	99·6%

PART 3.—DRAUGHT CONDITIONS DURING THE CAMPAIGN.

BY J. E. DOYLE AND W. J. COLLINS.

The draughting of the furnace was checked at the outgoing end at intervals during the test, but only the stack draught was continuously recorded. The points selected as important from this
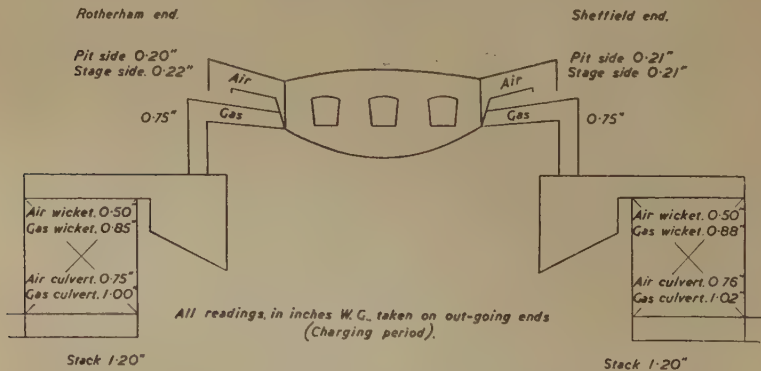
FIG. 12.—The Draughting Conditions.

point of view were the air downtakes (stage and pit sides), gas downtake, air and gas wickets, air and gas culverts about 4 ft. from the face of the checkers, and at the stack damper on the furnace side.

The downtake readings were taken about 1 ft. above the stage level. Slant gauges and U-tubes were used for all draught measurements, except at the stack, where a hydraulic recorder was installed.

Average readings at the various points are given below, and illustrated diagrammatically in Fig. 12 :

Average Pressures at Different Points in the Furnace.

	Rotherham End.	Sheffield End.
Air downtake :		
Pit side .	−0·20 in.	−0·21 in.
Stage side	−0·22 in.	−0·21 in.
Gas downtake	−0·75 in.	−0·75 in.
Air wicket .	−0·50 in.	−0·50 in.
Gas wicket .	−0·85 in.	−0·88 in.
Air culvert .	−0·75 in.	−0·76 in.
Gas culvert	−1·00 in.	−1·02 in.
Stack .	−1·20 in.	−1·20 in.

Part 4.—Details of Repairs to the Roof During the Campaign.

By J. E. PLUCK.

Complete details of the running repairs made to the roof during the campaign are given in Table XV. The first repairs (five days after gassing) were necessary on account of bricks slipping through at the time of gassing ; this was considered to be due to local extra expansions causing slack patches in the adjacent bricks. This was possible because the roof was bonded. If the roof had been built in straight rings any local expansion would have caused only the particular ring or rings to lift ; the adjacent rings would have remained stable. All bricks built in single rings act as independent arches, and their very existence depends on the pressure between the bricks, which therefore cannot fall out. The bonded roof shares such local pressures over a larger area, and thereby allows slack portions to occur. One method of overcoming part of this fault may be to increase the rise in the roof arch, and all bricks would have more taper and therefore be less likely to fall through. Although this is a serious fault with a bonded roof during its initial warming-up, the sharing of the load is an advantage during the latter part of a campaign when patches may be very thin.

After $8\frac{1}{2}$ weeks, on January 13th, 1940, the furnace was taken off for a repair to the bottom and a rammed silica block was put in at each end. Photographs were then taken (*see* Fig. 21). The roof was well glazed, but erosion was just beginning over the taphole and about a square yard at each end.

In the first $13\frac{1}{2}$ weeks there were only four small repairs to the roof of 19 bricks in all. Then the furnace sustained a serious explosion (one of several) owing to snow in a charging pan, and the roof had a severe bumping. The following 19 repairs can all be traced to this shaking. Owing to the repairs having to be carried out under hot conditions, the new bricks quickly spalled and the same patch

had to be repaired several times.   A glance at Table XV. will show
how often this occurred.

TABLE XV.—*Log of Repairs to the Roof During the Campaign.*

Period after Gassing.	Week Ending—	Nature of Repair.	No. of Bricks.
5 days	13/11/39	Several small patches in roof—12 in.	10
6½ weeks	1/1/40	12 in. in roof over middle door.	2
8 ,,	10/1/40	,, ,, ,, ,,	3
8½ ,,	13/1/40	Furnace off for block and bottom repair.	
9 ,,	16/1/40	Patch—2 squares—2 end arch	4
13½ ,,	19/2/40	Repairs to roof over middle door.	27
14½ ,,	25/2/40	Patch over middle door.	16
14½ ,,	26/2/40	,, ,, ,,	10
15 ,,	27/2/40	,, ,, ,,	27
15 ,,	28/2/40	,, ,, ,,	18
15 ,,	29/2/40	,, ,, ,,	67
15 ,,	29/2/40	,, ,, ,,	22
15½ ,,	1/3/40	,, ,, ,,	40
15½ ,,	3/3/40	,, ,, ,,	8
15½ ,,	3/3/40	Patch over Rotherham door.	21
15½ ,,	4/3/40	Patch over centre.	9
16 ,,	5/3/40	Patch Rotherham side of middle door.	80
16 ,,	6/3/40	Patch centre over Rotherham door.	76
17½ ,,	17/3/40	Roof repairs over middle door.	14
17½ ,,	18/3/40	,, ,, ,, ,,	4
18 ,,	21/3/40	Roof repairs over Rotherham door.	40
18½ ,,	22/3/40	Roof repairs over middle door.	26
18½ ,,	23/3/40	Roof repaired.	...
19 ,,	25/3/40	Roof grouted, patch in centre of Sheffield ramp.	...
19½ ,,	30/3/40	Put off for general repairs.	...
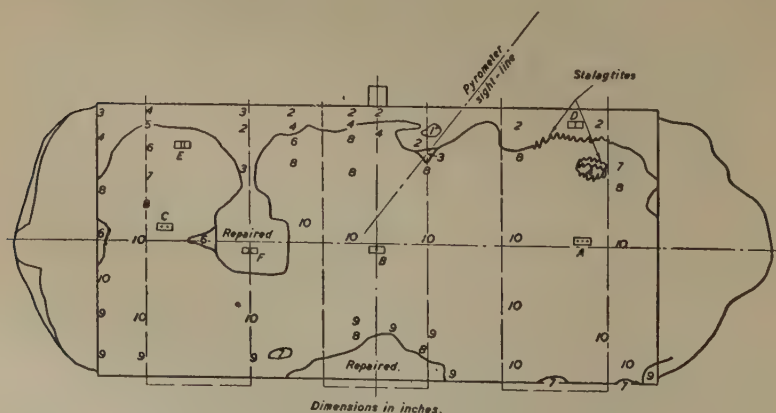
FIG. 13.—Thickness of Roof at End of Campaign.

After a life of $19\frac{1}{2}$ weeks the furnace was taken off for a general repair.

Before dismantling, after the furnace had cooled, the roof was still intact and was examined and photographed; certain bricks were selected and marked for samples. The thickness of various parts of the roof was estimated and the estimations were later checked against the measured thicknesses of the selected samples. The thickness of the roof is shown in Fig. 13; the two patches which were being continually repaired during the latter third of the campaign are here clearly shown. A photograph of the stalactites marked at one corner on the plan are shown in Fig. 23. The severe erosion immediately above the line of the back-wall pyrometer is illustrated in Fig. 24; a close-up of the area is shown in Fig. 25; this was the thinnest part of the roof. The patched area is shown in Fig. 26. At least 75% of the roof was still more than 8 in. thick at the end of the campaign. Unfortunately, the shape by this time had become very flat, and further repair was not considered worth while and would, in fact, have been very difficult to carry out.

REFERENCES (SECTION III.).

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Section IV.—Examination of Samples taken from the Roof at the End of the Campaign.

BY J. H. CHESTERS, PH.D., B.SC., B. W. METHLEY, F.I.C., T. R. LYNAM, F.G.S., T. W. HOWIE, B.SC., AND A. E. DODD, M.SC.(LOND.).

After the gas had been taken out of the furnace for a day or so, the roof was carefully examined and bricks from certain areas were marked as samples for laboratory work. The positions of the samples and their marking are shown in Fig. 14. Several bricks were taken from each area so that tests might be carried out by each of the interested laboratories, but most of the work was concerned with bricks taken from position B in the region where the temperature gradient had been recorded. Three bricks from this area

were used for the bulk of the tests.   The first sample was sawn
through in a plane perpendicular to the working face and parallel
to the 6 in. by 3-in. side of the 12 in. by 6 in. by 3-in. block.   These

Tapping side.

E (II)   D (I)

C(·)   E(X)   B (·)   A(···)

Charging side
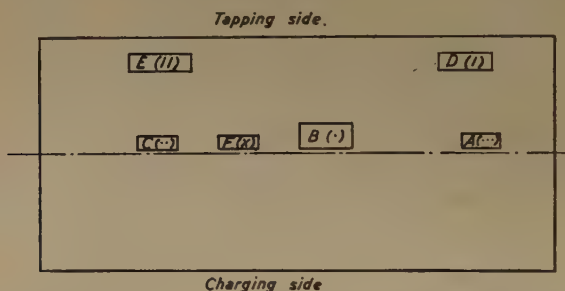
FIG. 14.—Positions in Roof from which Samples were taken.

pieces were again sawn into sections, by zones as follows (*see* Fig.
15) :

    Zone 1   Grey zone at the working face.
      „   2 ⎫
      „   3 ⎬ The section between the grey and yellow zones was subdivided
      „   4 ⎭   into three equal parts.
    .„   5   Clearly defined yellow zone.
      „   6   Red zone, the remainder of the brick.

Red   Yellow   Black   Black   Black   Grey
6   5   4   3   2   1

Cut   Cut   Cut   Cut
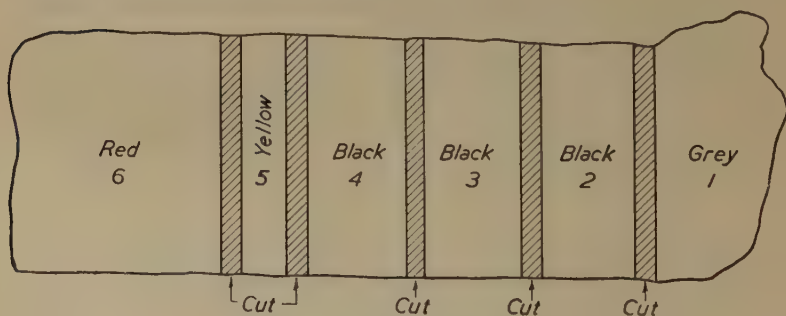
FIG. 15.—Method of Sampling.

It should be noted that this method of sectioning closely follows
that adopted by previous investigators; in the microscopical work
(Section VI. below) other less obvious zones have been located and
examined.

One set of the six zones was crushed and sampled for chemical
analysis.   The remaining sets were apportioned so that physical
testing could be carried out by each laboratory.   The results of
these tests are recorded below.

(a) *Length of Zones.*

The variation in the depth of each zone was very small in the centre bricks; in the areas where erosion had been more pronounced the zones were proportionately smaller, as is shown by the following measurements.

Position in Roof.	Zone 1, Grey.	Zones 2, 3 and 4, Black-Brown.	Zone 5, Yellow.	Zone 6, Red.
Centre	3·8 cm.	11·2 cm.	1·7 cm.	7·8 cm.
Worn area near back wall .	2·6 cm.	8·0 cm.	1·5 cm.	4·5 cm.

(b) *Chemical Analysis.*

The chemical analysis of each of the six zones of the used bricks, as found by Messrs. Steel, Peech and Tozer, is given in Table XVI. The general trend of these results will perhaps be more readily grasped by reference to Fig. 16. The iron-oxide determination

TABLE XVI.—*Chemical Analyses of Zones.*

Zone :	1, Grey.	2, Black.	3, Black.	4, Black.	5, Yellow.	6, Red.
SiO_2. % .	85·81	88·80	86·33	87·67	94·24	95·06
Al_2O_3. % .	0·29	0·21	0·68	1·32	0·74	0·86
FeO. % * .	7·59	5·65	6·43	4·50	1·41	0·77
TiO_2. % .	0·10	0·10	0·14	0·18	0·10	0·07
CaO. % .	3·46	3·00	3·75	4·04	2·20	1·60
MgO. % .	0·34	0·33	0·44	0·35	0·14	0·12
MnO. % .	0·41	0·35	0·47	0·22	0·11	0·02
SnO_2. % .	0·05	0·04	0·05	0·04	0·05	0·05
PbO_2. % .	0·28	0·25	0·24	0·23	0·20	0·15
CuO. % .	0·30	0·14	0·12	0·16	0·10	0·10
ZnO. % .	Nil	Nil	Nil	Nil	Nil	Nil
F_2. % .	0·07	0·06	0·09	0·07	0·07	Nil
SO_3. % .	0·07	0·06	0·05	0·06	0·04	0·55
P_2O_5. % .	0·18	0·13	0·18	0·13	0·03	0·01

* Total iron calculated to FeO. A separate analysis of the FeO and Fe_2O_3 content of Zone 1 gave the following results: FeO, 1·93%; Fe_2O_3, 6·38%.

shows that the amount of ferruginous matter present in the black zone was less than in the grey zone. Previous investigators have usually obtained an opposite result; the average iron-oxide figures given in nine earlier papers [1] are included in Fig. 16 and show this small divergence. Separate analyses carried out by the British Refractories Research Association, in which the ferrous and ferric oxides were separately determined, showed a regular change in the state of oxidation of the iron, as set out in the form of a ratio below:

State of Oxidation of the Iron in the Different Zones.

Zone	1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
FeO : Fe_2O_3 ratio .	0·35	0·34	0·18	0·13	0·10	0·11

The ratio of FeO to Fe_2O_3 in magnetite is 0·45; hence it would appear that even at the hot end of the brick the iron is not completely reduced to magnetite, although changes in the state of the iron probably occurred while the roof was cooling down.

It has generally been considered that the lime present in and absorbed by a silica brick in the roof of a basic open-hearth furnace becomes concentrated in the yellow band at a considerable distance from the exposed face. Thus, all except one of the six analyses quoted in the First Report on Refractory Materials [1] show a lime
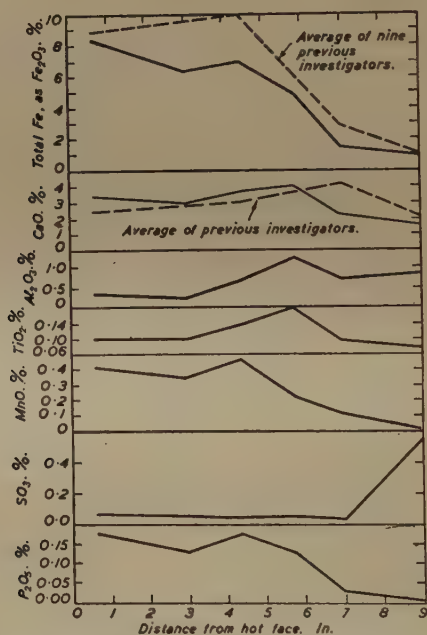
FIG. 16.—Distribution of Fluxes in the Zones of Used Roof Bricks.

concentration in the yellow zone; the exception indicates a concentration rather in the black zone. In the present work the lime concentration was found at a plane a little nearer to the hot face than the yellow zone. The narrowness of this calcareous band and its true nature are more fully discussed in Section VI., dealing with the microscopical examination of the used bricks. The migration of the lime from the hot face is closely simulated by the alumina and titania; the proportions of these oxides rise to a maximum just to the front of the yellow zone, as found by previous investigators. The small amount of manganese oxide taken up from the furnace atmosphere does not penetrate so far as the last-named

oxides; the percentage of MnO remains constant in the 3 or 4 in. of brickwork next to the working face and then drops rapidly. It will be noticed that the distribution curve of the MnO closely follows that of the iron oxide.

The acid radicals SO_3 and P_2O_5 have not generally been determined in previous studies of the zones of open-hearth roof bricks; in the present work interesting results have been obtained. In particular, a striking concentration of sulphates has been found at the cooler end of the brick; the proportion of SO_3 in each of the zones nearer to the working face was less than 0.2%, but in the red zone the figure suddenly increased to 0.55%. It is thought that the sulphur came from the furnace and passed through the roof rather than that it was drawn in from the melting-shop atmosphere; it should be mentioned that in making certain free-cutting types of steels pyrites was on one or two occasions added to the bath of the furnace. The P_2O_5 content of the used bricks remained fairly constant throughout the front half of the brick, but then fell to a mere trace. In no zone did the $P_2O_5 : CaO$ ratio approach that in the slag, neither was the P_2O_5 content a maximum in the zone in which the lime content was highest. This fact supports previous inferences from checker-dust analyses that the slagging agents present in the furnace atmosphere contain but a small proportion of molten basic open-hearth slag.

The determination of non-ferrous metals has given some interesting results; the volatile zinc oxide, found in such quantity in the flues, is quite absent from any zone in the roof itself. A curious feature, however, is the presence of lead oxide, which is found below stage level in positions even more remote from the furnace proper than is the zinc oxide; no explanation can be advanced for this apparent contradiction. Tin oxide is present throughout the roof, but in quite negligible amounts, while copper oxide appears to concentrate at the working face.

A separate analysis of a stalactite chipped off the roof shortly after it had cooled down gave the results set out below :

Chemical Analysis of Stalactite from the Roof.

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	TiO_2.	CaO.	MgO.	MnO.	Total.
86.89%	0.51%	6.58%	0.90%	0.16%	3.80%	0.54%	0.59%	99.97%

It will be seen that this stalactite had almost the same composition as the front zone of the brick, but the $FeO : Fe_2O_3$ ratio nearly corresponded with that of zone 4; this might well be attributable to rapid oxidation of the exposed surface of the stalactite while the furnace was cooling down. In the studies of Larsen and his co-workers,[2] already referred to, some of the stalactites examined were of similar composition to the grey zone, while some were definitely richer in fluxes. This suggests that the composition depends on the stage in the life of the stalactite; it is possible that

the flux content becomes progressively greater as the stalactite remains exposed to dust and vapour.

(c) *Refractoriness.*

The results obtained on cones cut from the various zones (Table XVII.) correspond with those reported by previous investigators.

TABLE XVII.—*Fusion Points of Cones cut from the Zones.*

Zone.	Laboratory *A.*	Laboratory *B.*	Laboratory *C.*	Average.
	°C.	°C.	°C.	°C.
1, grey	1730	1740	1735	1735
2, black	1720	1730	1735	1730
3, „	1700	1710	1690	1700
4, „	1680	1690	1690	1685
5, yellow	1700	1710	1720	1710
6, red	1710	1720	1730	1720

The refractoriness is fairly high throughout the brick, but the zone just to the front of the yellow band is definitely less refractory than the remainder. This feature is better demonstrated by the figures shown below, obtained on powdered samples :

Fusion Points of Cones made up from Powdered Samples.

Zone	1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
Fusion point,° C.	1690	1680	1670	1640	1700	1700

The decreased refractoriness of the hot end of the brick when tested in this manner is also noteworthy ; it would appear that under working conditions the nose of the brick is composed of a rigid network of cristobalite crystals, with interstitial semi-fluid ferruginous matter.

(d) *Refractoriness-under-Load.*

One of the co-operating laboratories (*C*) carried out a series of refractoriness-under-load tests on 1-in. cubes cut from each zone ; the tests were carried out in a gas-fired furnace with the results appended :

Refractoriness-Under-Load Data (28 lb. per sq. in.).

Zone	1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
Temperature, ° C.:						
Laboratory *A*	1700	...	...	...	...	1700
Laboratory *C*	1710	1720	1710	1700	1710	1720

It is curious that testing under load failed to show up the decreased refractoriness of zone 4 as clearly as the ordinary test without load. This may in part be due to the enforced use of small test-pieces.

(e) *Percentage Porosity.*

The cavernous nature of parts of the hot end of the used bricks led to considerable variations in individual results in the porosity determination; the extent of this variation and the average figures (in most cases for at least ten test-pieces) were as follows:

Porosity of the Zones.

Zone			1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
Variation.	%	.	10–14	5–11	9–14	11–21	23–24	23–24
Average.	%	.	10·6	9·7	10·1	12·9	23·8	23·6

The general decrease in the porosity at the hot end of the roof bricks is very marked and is in accord with the work of previous investigators; this decrease is evidently a result of flux absorption, and the change to the normal texture at the limit of flux penetration is very clearly defined.   However, calculation (*see* Appendix) shows that the actual weight of extraneous matter taken up by the roof is insufficient to account for a 10% drop in porosity, and it must be assumed that a certain amount of the fluid glaze formed on the face of the bricks is itself drawn up into the pores.

(f) *Permeability.*

The permeability determination is even more sensitive to the presence of fissures and cracks than is the porosity, and it was anticipated that the values obtained for this property would show considerable variation between different test-pieces cut from the same zone.   This proved to be the case, as will be seen from the following two sets of data:

Permeability of the Zones of the Used Bricks.

Zone			1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
Laboratory *A*		.	0·146	0·025	0·030	0·001	0·081	0·097
Laboratory *C*		.	0·072	0·107	0·190	0·002	0·182	0·107
Average		.	0·11	0·07	0·11	0·002	0·13	0·10

Nevertheless, the figures leave no doubt of the presence of a practically impermeable region between the black and yellow zones; this is the plane along which the lime and alumina concentrated, and the presence of a continuous narrow band of glass has been revealed in the course of the microscopical work (Section VI.).

(g) *Specific Gravity.*

Little information of value can be obtained from the determination of the true specific gravity of the zones (Table XVIII.) on account of the modifying influence of the iron oxide present.   The results obtained by the two laboratories show good agreement among themselves.

TABLE XVIII.—*Specific Gravity of the Zones of the Used Bricks.*

Zone.				Laboratory.		Average.
				A.	*B.*	
1, grey	.	.	.	2·52	2·51	2·52
2, black	.	.	.	2·41	2·42	2·42
3, ,,	.	.	.	2·45	2·43	2·44
4, ,,	.	.	.	2·41	2·42	2·42
5, yellow	.	.	.	2·35	2·33	2·34
6, red	.	.	.	2·33	2·33	2·33
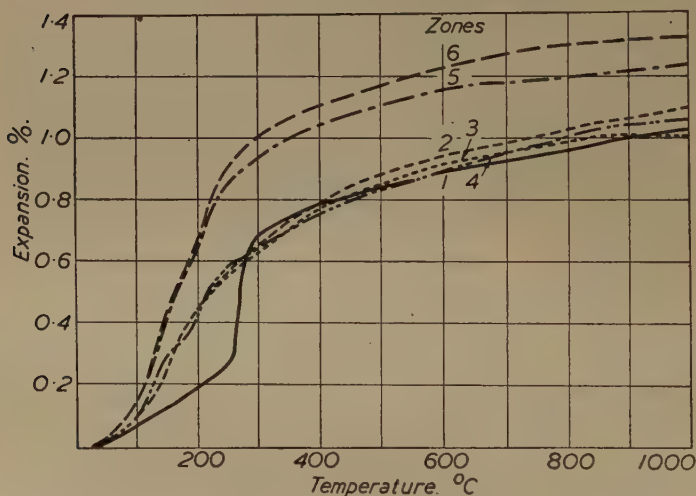
FIG. 17.—Thermal-Expansion Curves of the Zones of a Roof Brick.

(h) *Thermal Expansion.*

The change in mineral constitution from zone to zone is reflected in the expansion behaviour, in consequence of the differences in the expansile properties of the forms of silica. The results obtained by the three laboratories are collected in Table XIX., and one set of expansion curves is shown in Fig. 17. It will be seen that the cold end of the brick has the highest overall expansion, while the first four zones (*i.e.*, to the limit of the iron-oxide penetration) have a total expansion between 1·00% and 1·05%. The very rapid expansion of the cristobalite in zone 1 is well illustrated. This inversion commenced at 260–270° C. and roughly agrees with the empirical relationship between the temperatures of formation and inversion proposed by Pierce and Austin.[3] This relationship is :

$$t_i = 120 + 0.090\,t,$$

where t_i = temperature at which inversion begins,
  t_f = temperature of formation (or equilibrium).

TABLE XIX.—*Thermal Expansion to* 1000° C. *of Zones of Used Roof Bricks.*

Zone.				Laboratory.			Average.
				A.	*B.*	*C.*	
				%.	%.	%.	%.
1, grey	.	.	.	1·02	1·23	0·89	1·05
2, black	.	.	.	1·09	1·06	0·93	1·03
3, ,,	.	.	.	1·00	1·06	0·88	0·98
4, ,,	.	.	.	1·07	1·05	0·95	1·02
5, yellow	.	.	.	1·26	1·31	1·22	1·26
6, red	.	.	.	1·32	1·23	1·10	1·22
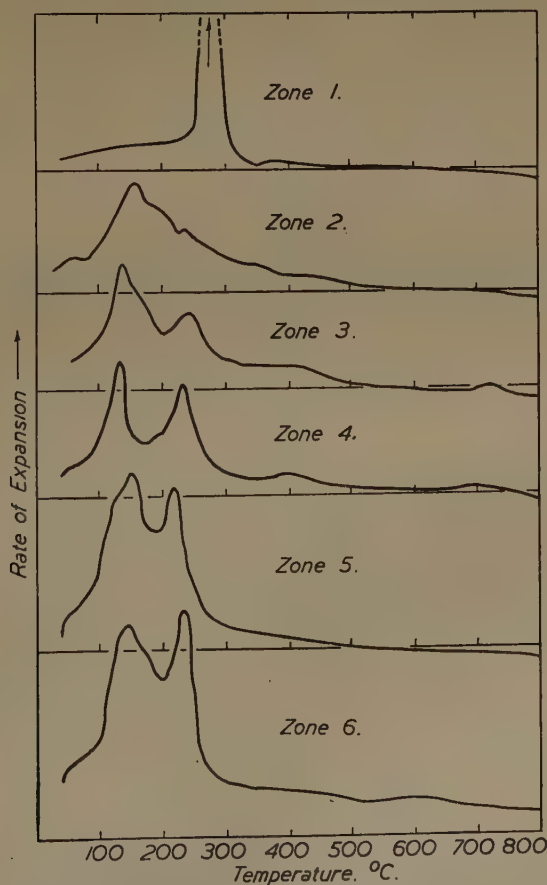
FIG. 18.—Coefficient-of-Expansion Curves for the Zones of a Roof Brick.

An inversion temperature of 260–270° C. would correspond with a temperature of formation of 1550–1650° C.

The significance of the silica inversions is even better appreciated from the curves showing the change in the coefficient of expansion with the temperature. A set of these curves for the six zones is shown in Fig. 18. The grey zone, in which the silica is present entirely as cristobalite, suffers a very marked and rapid expansion at 250–300° C. Zone 2, which is rich in tridymite, shows a less rapid and less accentuated expansion between 100° and 200° C.; this is typical of the tridymite inversion. The cristobalite peak is only just discernible in the curve obtained for this zone, and the gradual development of this peak in the succeeding zones is most interesting. A further feature which may be noticed is the variation of the temperature at which the cristobalite inversion reaches a maximum with the distance from the working face; this variation will perhaps be more readily followed from the following figures :

Variation in the Inversion Temperature of Cristobalite with the Distance from the Hot Face.

Zone . . .	1, Grey	2, Black	3, Black	4, Black	5, Yellow	6, Red
Temp. of max. coeff. of expansion. ° C. .	270	240	240	230	220	230

The fact that the inversion temperature of cristobalite is in some measure proportional to its temperature of formation has been known for some time, but the cause of this anomaly has not yet been explained.

REFERENCES (SECTION IV.).

(1) First Report on Refractory Materials, p. 26, *Iron and Steel Institute*, 1939, *Special Report No.* 26.
(2) B. M. LARSEN, F. W. SCHROEDER, E. N. BAUER and J. W. CAMPBELL : *Mining and Metallurgical Investigations*, 1925, *Bulletin No.* 23.
(3) R. H. H. PIERCE and J. B. AUSTIN : *Journal of the American Ceramic Society*, 1936, vol. 19, p. 276.

APPENDIX.—*Calculation to Show that the Decrease in Porosity of the Hot End of the Used Roof Bricks is too Great to be Attributed to Simple Slag Penetration into the Pores.*

Consider 100 g. of the unused brick, the properties of which may be assumed to be identical with those of zone 6 (*i.e.*, porosity 23·6%, specific gravity 2·31).

The total volume (air + solid) of this 100 g., V, is given by the following equation :

$$\frac{23\cdot6}{100} = \left(1 - \frac{100}{V} \times \frac{1}{2\cdot31}\right)$$
$$V = 56\cdot6.$$

If the hot face merely consists of original brick with slag absorbed

into the pores, this volume of brick, after use at the hot face, will
weigh W g. :

$$\frac{10 \cdot 6}{100} = \left(1 - \frac{W}{56 \cdot 6} \times \frac{1}{2 \cdot 48}\right).$$

since the porosity of zone 1 = 10·6%
and its specific gravity = 2·48.
Whence W = 125·5 g.

Hence, on the assumption that the decrease in porosity at the hot
face is entirely due to flux absorption, each 100 g. of brickwork has
in this zone taken up 25·5 g. of flux. This is approximately twice
the flux pick-up as determined by analysis, hence the very pro-
nounced decrease in porosity at the hot face is in a large measure
attributable to partial fusion and recrystallisation of the original
mineral constituents in the brick.

Section V.—The Results of X-Ray Studies of the Raw Material and of Used Silica Brick from the Open-Hearth Furnace Roof.

By A. H. JAY, Ph.D., F.Inst.P.

(Figs. 27 to 30 = Plates XXIV. and XXV.)

A.—*Raw Material and Structural Changes after Firing.*

This examination, which was carried out by the back-reflection
X-ray method, was made to determine the crystalline texture of the
raw material and the degree of conversion of the quartz after firing
with respect to the size of the crushed particles.

Raw Material.

It has been the author's experience that the size and perfection
of the quartz crystals in silica rocks can be used as a useful guide to
the probable degree of conversion undergone by the raw material
during a firing treatment. In the preliminary study of silica rocks
the pinhole transmission method was used,[1] and it was found that
this rock contained a major portion of large crystals which were
warped or internally broken into smaller units. For this particular
work an additional method, consisting in taking back-reflection
photographs, has been used.

Typical back-reflection photographs are reproduced in Fig. 27.

It was found that the spot reflections were in some cases in the
form of continuous arcs of circles, while in others the arcs consisted
of a large number of spots. In all cases there was evidence of
strong preferred crystal orientation, varying from a continuously
changing crystallographic direction to a step-like change. The
change in orientation in any one grain or micro-crystal appeared to
vary from a few degrees to, say, 30°. This grain characteristic may

be interpreted as showing internal breakdown of visible grains. These quartzites showed pronounced wavy extinction.

Fired Samples.

The samples were fired with the bricks used in the furnace under investigation. Constitutional changes were determined from photographs, *see* Fig. 28, taken in a standard powder camera.[2] The observations made are recorded in Table XX.

TABLE XX.—*Constitution of Pebbles and Crushed Material after Firing.*

Sample.	Constitution.		
	Quartz. %.	Cristobalite. %.	Tridymite. %.
A.—Ground Material.			
Grading : $\frac{1}{2}$ in.–$\frac{1}{4}$ in.	20	70	10
$\frac{1}{4}$ in.–7-mesh	25	60	15
7–25-mesh	25	50	25
25–72-mesh	20	40	40
—72-mesh	5	30	65
B.—Lump Rock.			
Centre of pebbly rock, $1\frac{1}{2}$ in. $\times$ 1 in. $\times$ 1 in.	30	60	10
Centre of ordinary rock, $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in.	50	45	5
Centre of pebble, 2 in. $\times$ 1 in. $\times$ 1 in.	55	45	...

Discussion.

Ground samples.—There does not appear to be any direct correlation between the ground particle size and the degree of quartz conversion.

There is sufficient evidence to show that the smaller the ground particle size the greater is the conversion to tridymite.

Lump Rock.—The degree of conversion of quartz at the centre of a large lump is relatively high.

The amount of tridymite formed is very small. This is in agreement with the results from ground samples.

B.—*Used Silica Brick taken from the Open-Hearth Furnace Roof.*

This examination was carried out to determine (*a*) the constitution of and (*b*) the crystalline development in the six chosen zones of a used silica roof brick. The powders were taken out of those used for chemical analysis.

Constitution.

The samples were received in powder form and were examined by the use of a cobalt K_a radiation in a 9-cm. dia. powder camera.

A selection of photographs is given in Fig. 29, and the observations made are included in Table XXI.

TABLE XXI.—*Constitution of Zones from Used Roof Brick.*

Zone.	Quartz.	Cristobalite.	Tridymite.	Other Substances.
6, cool end	Very small (5%)	Medium	Medium	⎫ Very small, not identified
5	Very small	Medium	Medium	
4	Possible trace (2%)	Possible trace (5%)	Very large	Glass
3	...	...	Very large	⎫ Very small, not identified
2	...	...	Very large	⎭
1, hot end	...	Very large	...	Magnetite, small amount.

Discussion.—(1) The X-ray patterns of zones 6 and 5 are remarkably similar.

In consideration of the author's previous experiences, which indicate that the constitution of zone 6 is not materially changed during use, it can be stated that the original brick was hard-fired, with approximately equal amounts of cristobalite and tridymite and less than 5% of residual quartz.

The crystalline impurities are present only in very small amounts and have not been identified.

(2) The X-ray pattern for zone 4 shows a striking change and only tridymite is definitely observed.

The absence of other patterns, together with an increase in the general background scattering, suggests the presence of an amorphous or glassy phase, high in silica and containing the impurity elements.

(3) There is no major constitutional change in passing from zone 4 to zones 3 and 2.

It is possible that the increased clarity of the line pattern of tridymite and the appearance of other weak lines is an indication of the crystalline development of tridymite and the crystallisation of other phases not identified.

(4) Cristobalite is the principal crystalline phase in zone 1. Magnetite is observed in small amount.

(5) These results suggest that there are three regions of distinct crystallographic character in a used silica roof brick : (*a*) zone 1, which is mainly cristobalite, (*b*) a region comprising zones 2, 3 and 4, and consisting mainly of tridymite, and (*c*) a region comprising zones 5 and 6, which is unchanged or only slightly changed from the original brick if this has been reasonably hard-fired.

Crystal Size.

Information on the crystalline texture of the various parts of the brick was obtained from an examination of thin sections by the pin-

hole transmission method. In a number of cases where the grog and matrix could be distinguished, these areas were examined separately (Fig. 30); the data obtained are given in Table XXII.

TABLE XXII.—*Crystal Size of Zones from Used Roof Brick.*

Zone.	Quartz.	Cristobalite.	Tridymite.
6 (a) Grog	Medium/large	Very small	...
(b) Matrix	Large	Very small	Small
5 (a) Grog	Large	Very small	...
(b) Matrix	Large	Very small	Small
4 (a) Grog	Large	Very small	Small
(b) Matrix	...	...	Small/medium
3	...	...	Medium
2	...	...	Medium/large
1	...	Large	...

Discussion.—(1) The quartz remaining in zones 6, 5 and 4 consists of large crystals.

The observations confirm the author's previous experiences that in a given quartzite the largest crystals are among those last to be converted.

(2) It is interesting to note that although cristobalite appears before tridymite in the conversion process of quartz during the firing of the brick, its crystal size remains very small, while that of tridymite is definitely larger, *see* zones 6, 5 and 4.

(3) The results indicate that the crystalline texture of tridymite increases in passing from zones 6 and 5 through zones 4 and 3 to zone 2.

(4) Cristobalite in zone 1 has a large crystal size.

REFERENCES (SECTION V.).

(1) A. H. JAY and J. H. CHESTERS : *Transactions of the Ceramic Society,* 1938, vol. 37, p. 218.
(2) A. J. BRADLEY and A. H. JAY : *Proceedings of the Physical Society,* 1932, vol. 44, p. 563.
    A. J. BRADLEY and W. L. BRAGG : *Journal of the Iron and Steel Institute,* 1940, No. I., p. 70.

Section VI.—The Microstructure of Used Roof Bricks.

BY W. HUGILL, M.MET., F.R.M.S., A.R.P.S.

(Figs. 31 to 47 = Plates XXVI. to XXVIII.)

When the bricks were sectioned longitudinally ten zones were readily distinguished from each other by marked differences in colour. In Section IV. analyses are given for bricks divided into six zones. Thin sections were prepared through the whole of the zones, and

when these were examined under the microscope it was found that at least two zones which were not differentiated in the original six groups had considerable significance. Hence, complete or partial analyses were made of nine of the remaining zones, zone C being irregular and difficult to separate from B and D. Zone E also was irregular, but material from this zone was separated from tridymite by means of a suitable liquid. The resulting fraction, which was contaminated with a small amount of quartz, was analysed. It will be shown later how the true composition of this material was determined. The appearance and colour of the zones are described in Table XXIII.; Fig. 31 illustrates the section.

TABLE XXIII.—*Description of Zones in Used Roof Brick.*

Zones of Section IV.	Zones of present Section.	Length. Mm.	Observations.
1	A	44	Light grey; sharply separated from next zone.
2	B	73	Black in colour; forms a curved to sinuous junction with C.
3 & 4	C	6	Thin and somewhat irregular brown zone.
	D	32	Colour greenish-grey; irregular in outline on surface joining C and practically straight where it joins E.
	E	5	Thin and fairly straight orange-coloured zone.
5	F	20	Pale-yellow.
	G	19	Purple.
6	H	16	Pink.
	I	7	Purple.
	J	30	Pink.

The chemical composition of the zones is given in Table XXIV., and is also graphed in Fig. 19.

Examination of the Zones in a Thin Section under the Microscope.

The zones, denoted A to J as shown in Fig. 31, revealed the following characteristics under the microscope :

Zone A.—The main constituent of this zone is cristobalite. This is now subdivided into minute grains, owing to passing through the $\beta-\alpha$ transition, which occurs at about 240° C. Groups of these granules form larger grains and these aggregates are surrounded by films of magnetite/ferrous-oxide solid solution (wüstite), *see* Fig. 32. In some places the boundary contains reddish-brown patches, which under a high magnification are seen to have the appearance of a lamellar eutectic (Fig. 33). There are occasional clusters of minute crystals which possibly can be referred to fayalite ($2FeO.SiO_2$), *see* Fig. 34, where cristobalite occurs at the top and a mass of magnetite, which is black, at the bottom. Also, close to the hot face a few groups of minute crystals of a deep red-brown colour occur.
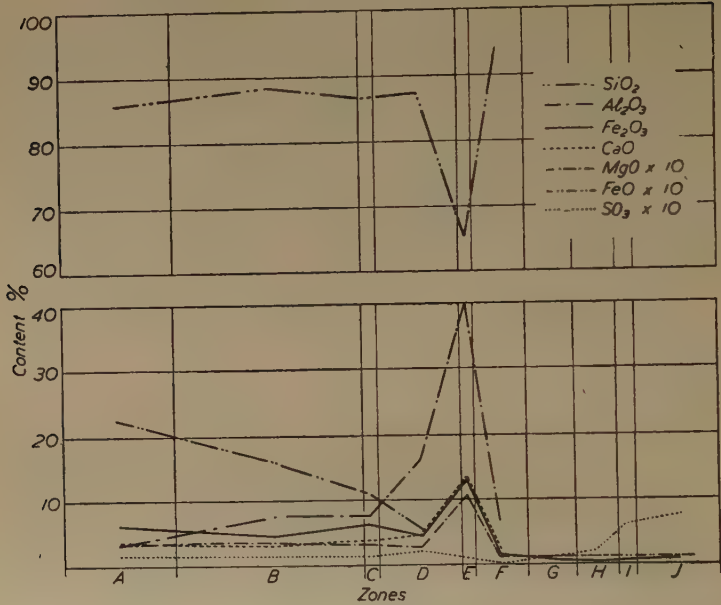
Fig. 19.—Chemical Compositions of the Zones of a Used Roof Brick.

TABLE XXIV.—*Chemical Composition of the Zones of the Roof Brick.*

Zone :	A.	B.	C.*	D.*	E.†	F.	G.	H.	I.	J.
SiO₂. % .	85·92	88·47	86·93	87·70	65·20	94·51				
TiO₂. % .	0·11	0·12	0·16	0·23	0·80	0·11				
Al₂O₃. % .	0·35	0·71	0·77	1·63	4·00	0·68				
Fe₂O₃. % .	6·43	4·74	6·27	4·40	13·33‡	1·47	0·88	0·58	0·82	0·96
CaO. % .	3·75	3·20	3·84	4·61	13·60	2·48				
MgO. % .	0·34	0·35	0·34	0·29	1·07	0·12				
Loss on ignition. % .	0·02	0·15	0·11	0·06	0·27	0·22				
FeO. % .	2·27	1·61	1·14	0·57	N.d.	0·14	0·11	0·11	0·11	0·11
MnO. % .	0·33	0·30	0·41	0·22	0·27	Nil				
P₂O₅. % .	0·20	0·16	0·20	0·13	N.d.	0·03	Nil	Nil	Nil	Nil
SO₃. % .	0·19	0·16	0·15	0·23	N.d.	0·02	0·10	0·24	0·61	0·76

* Zones *C* and *D* are mixed in the above analyses, owing to their irregular boundary, and *C* also contains some of zone *B* for the same reason.

† This analysis does not represent zone *E* as a whole, but consists of yellow glass contaminated with a small amount of quartz which was separated from zone *E*. In Fig. 19 these analyses are shown graphically; the oxides other than silica, ferric oxide and lime are multiplied by 10, so that variations in composition can be seen more clearly.

‡ Only the total iron as ferric oxide was determined, as the sample was too small for a separate determination of FeO.

These appear to be pseudomorphs of ferric oxide after magnetite. Like magnetite, but unlike hematite, they are cubic and in this

respect correspond to martite [1] (Fig. 35).   The total amount of martite and fayalite in this zone is very small, the ferruginous matter consisting mainly of wüstite and secondly of the lamellar eutectic mentioned previously.   It is noteworthy that large crystals of tridymite, which constitute the main form of silica in zone B, are found in zone A.   In this case, however, the crystals maintain the external size, shape and characteristic twinning of tridymite, but are actually transformed to cristobalite.   This can be seen in Fig. 36.   The junction between zones A and B is clearly defined, as can be seen in Fig. 31, the grey colour of zone A contrasting sharply with the black colour of zone B.   This junction is shown in Fig. 37 between crossed nicols; the upper portion contains large tridymite crystals while the lower portion consists of cristobalite grains.

Zone B.—This zone is black in colour and under the microscope is characterised by large crystals of tridymite.   These occur as arrow-head forms and, when differently orientated, as long lath-shaped crystals.   All tend to have their long axis perpendicular to the hot face (Fig. 38).   Interspersed between these crystals there are a black ferruginous material which is possibly wüstite, patches of laminated eutectic and a dark brown glass.   Large ganister fragments occur sparingly in this zone.   They retain their shape, but consist of glass with crystals of tridymite in them which are of smaller size than those in the matrix.   The boundary between this zone and zone C is irregular.

Zone C.—This zone is of a brown colour and is thin (about 6 mm.) and takes an irregular course.   The free silica is present as tridymite in large crystals, but of less size than in zone B.   The brown colour is produced by a crystalline mixture of tridymite and mellorite, [2] which is a silicate containing mainly ferric oxide and lime with small amounts of ferrous oxide, titanic oxide and alumina.   This eutectic has a lamellar structure which is more clearly defined than that produced by mellorite-cristobalite eutectic; it is shown in Fig. 39.

Zone D.—The general colour of this zone is greenish-grey.   It contains a considerable amount of the mellorite-tridymite eutectic and practically no magnetite/ferrous-oxide solid solution.   Mellorite contains some ferrous oxide, the proportion of which can vary; when this increases the tendency is to produce a blue-green colour and a lower refractive index.   When the ferrous oxide content decreases with corresponding increase in ferric oxide, the red-brown colour predominates and there is a corresponding increase in the refractive indices.   This probably is the cause of the difference in colour between zone D and zone C.

Zone E.—This zone is only a few millimetres deep and is of an orange-yellow colour.   Under the microscope the colour is seen to be due to an almost continuous layer of deep yellow glass; this is only interrupted by coarse ganister fragments.   Patches of this yellow glass are indicated by arrows in Fig. 40.   It is noteworthy that brick ($3Y$) had fractured at this zone, and brick ($2X$) also showed a

crack at this zone. This appeared to be at or near the limit reached by iron oxides, lime, &c., absorbed from the furnace.

Zone F.—This zone is pale yellow. There is a small amount of unchanged quartz in the coarser ganister fragments. A considerable amount of tridymite is present in the matrix in medium-sized crystals and there is a large amount of glass of a pale yellow colour. The latter appears to be glassy matrix from the lower portions of the brick which has been displaced by the incoming iron-oxide-rich glass seen in zone *E*. No crystals which could be referred to calcium meta-silicate were observed in this zone. A few coarse grains of quartz remain, one of which is shown at the lower right-hand corner of Fig. 41. The matrix contains a considerable amount of tridymite.

Zone G.—The colour of this zone is dark purple. The coarse ganister fragments contain a small amount of unchanged quartz with borders of cristobalite. In the lower portion of this zone the tridymite crystals are larger than in the upper portion. The ferruginous matter in the matrix has collected into distinct aggregates of hematite. This tendency to aggregation of the ferruginous matter is clearly indicated in Fig. 42.

Zone H.—This zone is pink in colour, and the ferruginous matter appears to be dispersed throughout the matrix in this section as minute crystals of hematite. There is a good development of tridymite crystals in the matrix. The coarser ganister fragments contain numerous remnants of unchanged quartz with some cristobalite and with small tridymite crystals among them. Fig. 43, between crossed nicols, shows a large fragment which has partly changed to tridymite and Fig. 44, also between crossed nicols, illustrates an area of the matrix with well-developed tridymite.

Zone I.—This consists of a layer 7 mm. deep which is of a purple colour. Here, as in the case of zone *G*, the ferruginous matter is mainly aggregated in the matrix (*see* Fig. 45, ordinary light). The matrix also contains a fair amount of tridymite in small crystals. The coarse ganister fragments contain slightly more residual quartz and less tridymite with more cristobalite than those in zone *H*.

Zone J.—Here the brick has the relative proportions of quartz, tridymite and cristobalite of an unused brick, but the matrix in mass is coloured pink. The ferruginous matter is distributed throughout the matrix as a red stain, which is barely perceptible in thin section. Fig. 46 depicts a coarse ganister fragment containing unchanged quartz and Fig. 47 a patch of the matrix showing development of tridymite, both under crossed nicols.

Discussion of the Factors which Cause the Formation of Zones.

From a study of the thin sections under the microscope, combined with a knowledge of the composition of the zones (from chemical analysis) and the known transformation of silica at certain tempera-

tures, it is considered that three main factors contribute to the pro-
duction of zones in silica roof bricks :

    (*a*) The effect of a temperature gradient from the hot face
to the back of the brick.
    (*b*) The effect of the ingress of inorganic oxides as dust or
vapour into the hot face of the brick.
    (*c*) The effect of gaseous products of combustion passing
through the brick.

  (*a*) The effect of temperature is shown visually by the sharp line
of demarcation between zones *A* and *B* in Fig. 31 and by the change
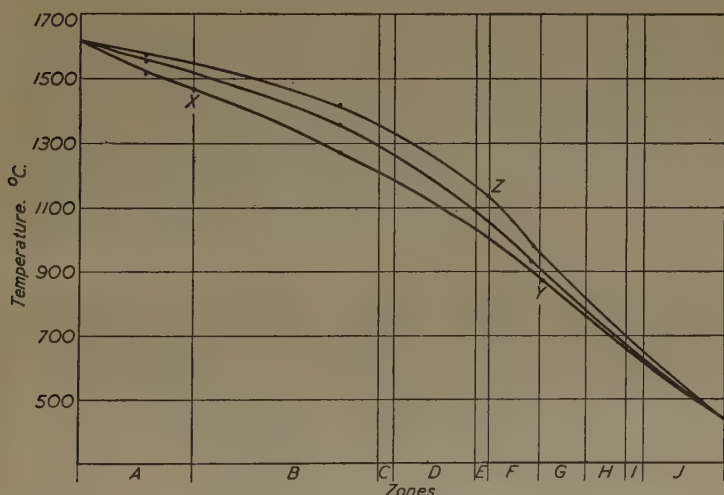
FIG. 20.—Maximum, Minimum and Average Temperatures attained in
Various Parts of a Roof Brick.

in the microstructure between these zones in Fig. 37.   It is also
indicated by the point marked *X* on the lower curve in Fig. 20.
These curves show the maximum, minimum and average tempera-
tures attained in various parts of a roof brick (near to the brick used
for micro-examination) during the last ten weeks of the campaign.
A second point *Y* (temperature 875° C.) on the lower curve corre-
sponds with an increase in the proportion of tridymite in the matrix
of the brick as seen under the microscope; from *Y* to *X* not only
does tridymite increase in amount but also the individual crystals
show a marked increase in size.   These points *Y* and *X* represent
temperatures of 875° and 1470° C., respectively;   in this range
tridymite is the stable phase.   The point *X* at a temperature of
1470° C. marks the thermal limit of stability of tridymite, and from

here to the hot face the silica is in the form of cristobalite. Large crystals of tridymite which have been carried with the melt from zones B, C and D into zone A, while maintaining most of their external shape and twinning, are transformed to cristobalite on passing through the zone boundary the temperature of which corresponds to the point X. The lower curve in Fig. 20 is of more significance than the upper or the mean curve in so far as changes in the form of silica are concerned, owing to the fact that these changes require a time as well as a temperature factor. The higher temperatures would be of short duration in any zone, whereas the lower-temperature curve represents a longer time factor. When the effect of temperature is considered along with the second main factor, (b), then the conditions are very different and the maximum temperature attained in a zone may have significance, as will be shown later.

(b) The effect of inorganic dust or vapour is shown by both the analyses and the microstructures of the zones. Two chief additions to the brick from this cause are iron oxide and lime. The first of these can exist in more than one state of oxidation, ferrous and ferric, and these two oxides can form solid solutions with each other. The stable form at high temperatures is magnetite, but under certain conditions marked departures from magnetite (Fe_3O_4 or $FeO.Fe_2O_3$) can occur. As shown in the analysis, the iron oxide in zone A after cooling to atmospheric temperature consists of 6.43% as Fe_2O_3 and 2.27% as FeO. These are in the molecular ratio of about $4Fe_2O_3$ to 3FeO. The microscope, however, shows that some of the ferric oxide is combined in a lime/ferric-oxide/silica complex, and other tests (notably that for magnetic susceptibility) show that the ferrous oxide predominates over the ferric in the black opaque material in this zone. In zones A and B the ferrous oxide and ferric oxide remaining after allowing for the proportion required in the lime/ferric-oxide/silica complex have the molecular ratio FeO : Fe_2O_3 equal to $1 : 0.7$ and $1 : 0.75$, respectively, while in zone C it is $1 : 2.2$ and in D there is practically no ferrous oxide. About 4.0% of ferruginous material can be extracted by means of a magnet from zone A, about 2.6% from zone B and none from zones C and D. Against this, however, it must be mentioned that the lime/ferric-oxide/silica complex can take up some ferrous oxide, the amount probably increasing with increasing alumina, and as a result there is a corresponding decrease in the proportion of ferric oxide taken up. The complex mellorite-tridymite eutectic, as a crystalline substance, appears to attain maximum development in the greenish-grey zone D, and it is from this zone that liquid is subsequently supplied to the hot face for the formation of stalactites. This eutectic of mellorite-tridymite contains about 68.5% of mellorite and 31.5% of excess silica, and melts at $1160°$ C. These proportions may vary with a change in composition of the mellorite and also with a change from tridymite to cristobalite, and therefore the melting temperature may also alter slightly. The original matrix of the brick is liquefied and

PLATE XXI.
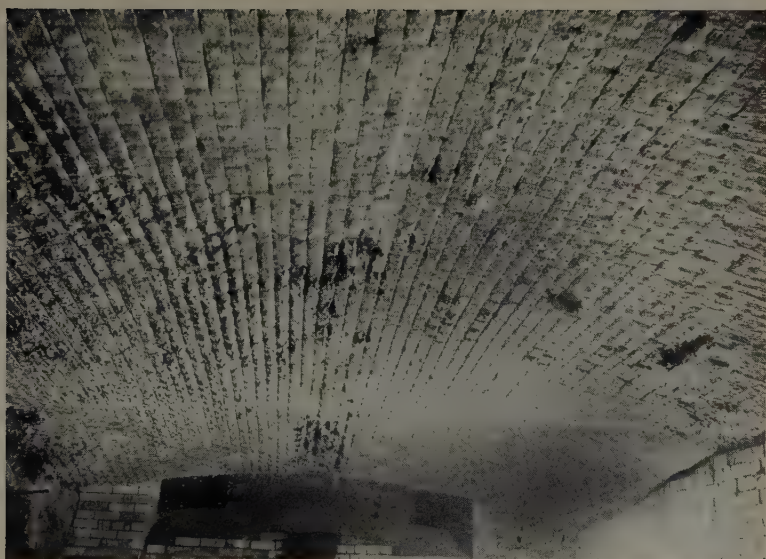
FIG. 21.—Appearance of Roof after 8½ Weeks' Working.

FIG. 22.—Dust Collected from Downtake by Aspiration.   × 10.

PLATE XXII.

FIG. 23.—Stalactites near the Tapping Side, Sheffield end.

FIG. 24.—Severe Erosion above the Tap-Hole.

[*Basic O.H. Roofs, Section III.*

PLATE XXIII.

Fig. 25.—Close-up of Roof above the Tap-Hole.

Fig. 26.—Patched Area at End of Campaign.

PLATE XXIV.
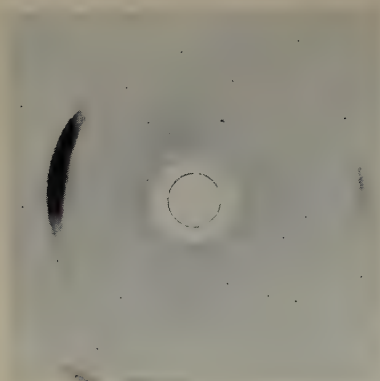
FIG. 27(a).—Quartzite Pebble.
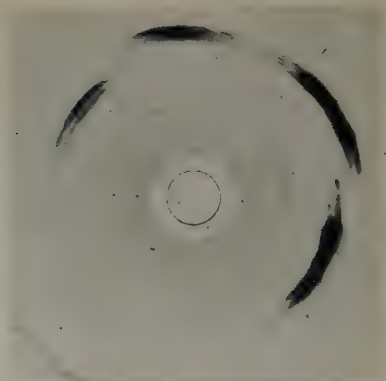
FIG. 27(b).—Quartzite Pebble.
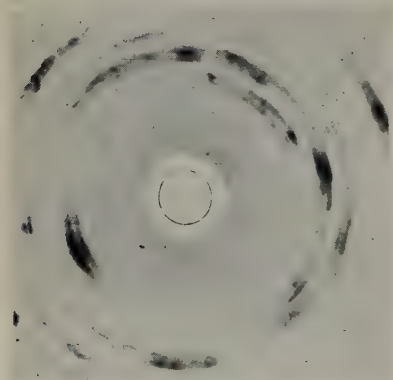
FIG. 27(c).—Quartzite Pebble Rock.
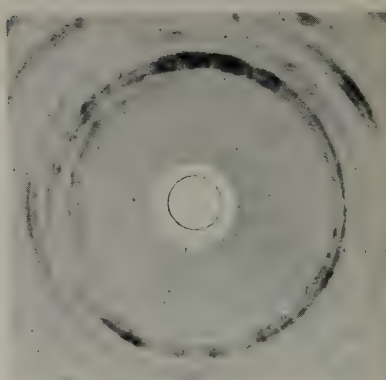
FIG. 27(d).—Quartzite Normal Rock.

FIG. 27 (a to d).—X-Ray (Back-Reflection) Photographs of Raw Quartzite.
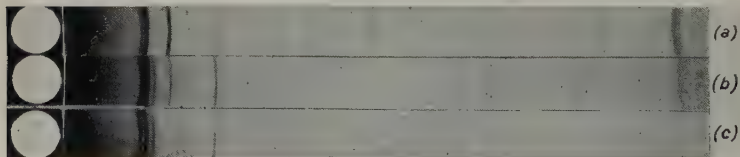
FIG. 28.—Debye-Scherrer X-Ray Patterns of Kiln-Fired Quartzites. (a) Much residual quartz. (b) Little residual quartz. (c) Trace of quartz with much tridymite.

[*Basic O.H. Roofs, Section V.*

PLATE XXV.
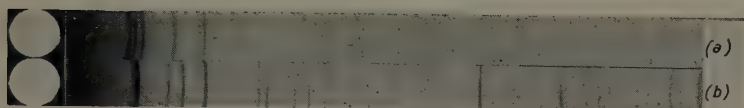
FIG. 29.—Debye-Scherrer X-Ray Patterns of Used Silica Roof Brick.
(a) Tridymite.   (b) Cristobalite.
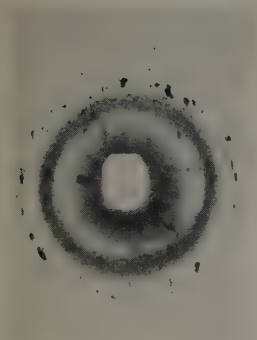
FIG. 30(a).—Zone 6; 'grog.
Large spots indicate quartz.
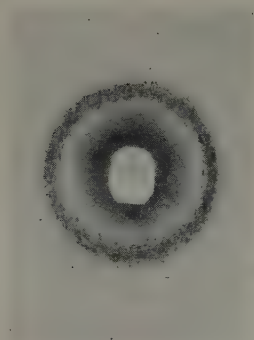
FIG. 30(b).—Zone 6; matrix.
No quartz.
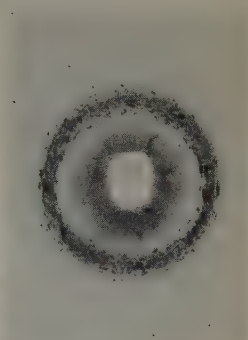
FIG. 30(c).—Zone 3; medium-
sized tridymite crystals.
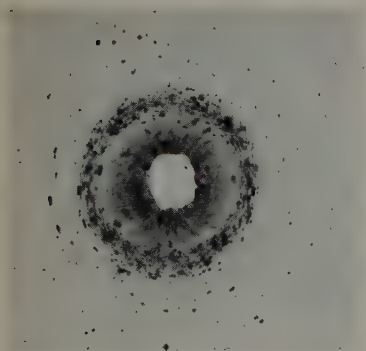
FIG. 30(d).—Zone 2; medium-large tridymite
crystals.
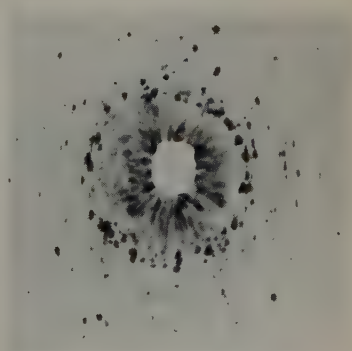
FIG. 30(e).—Zone 1; large cristobalite
crystals.

FIG. 30 (a to e).—X-Ray (Pin-Hole Transmission) Photographs of Used Quartz Brick.

[Basic O.H. Roofs, Section V.

PLATE XXVI.

A — Grey.

B — Purplish-black

C — Brownish-green

D — Greenish-grey

E — Orange

F — Yellow

G — Dark purple

H — Purplish-pink

I — Purple

J — Pink
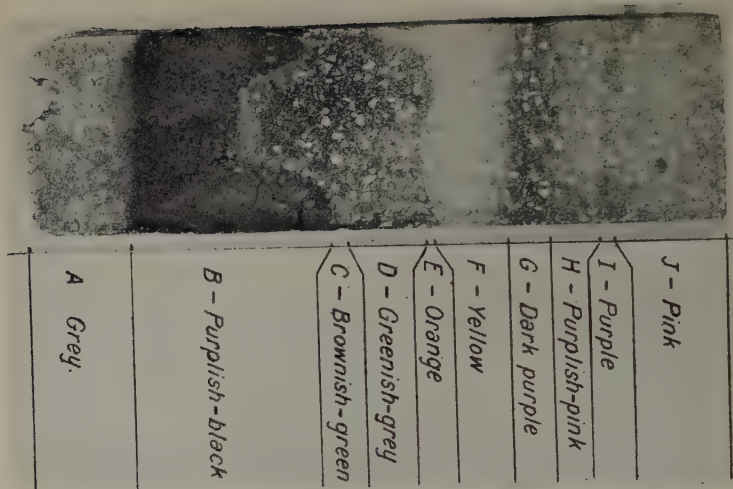
Fig. 31.—Zones in Roof Brick.
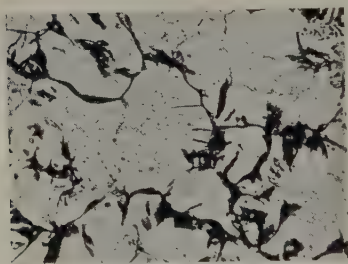
Fig. 32.—Cristobalite Grains in Wüstite Matrix.   × 50.
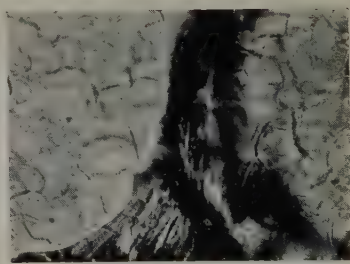
Fig. 33.—Lamellar Eutectic of Mellorite and Cristobalite.   × 500.
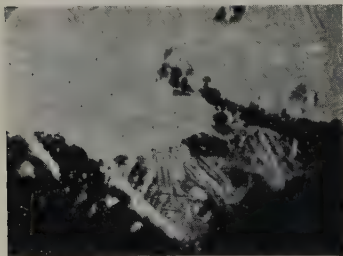
Fig. 34.—Fayalite Crystals and Magnetite. × 500.
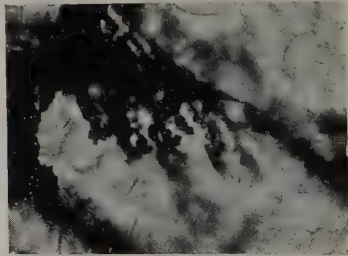
Fig. 35.—Martite Pseudomorphs after Magnetite.   × 500.

Figs. 32 to 35.—Constituents in Zone A.   Ordinary light.

(Figs. 32 to 35 reduced to two-thirds linear in reproduction.)

[Basic O.H. Roofs, Section VI.

PLATE XXVII.

FIG. 36.—Cristobalite in Zone *A* formed from large crystals of tridymite originally in Zone *B*. Remains of triplets of tridymite visible. Ordinary light. × 50.
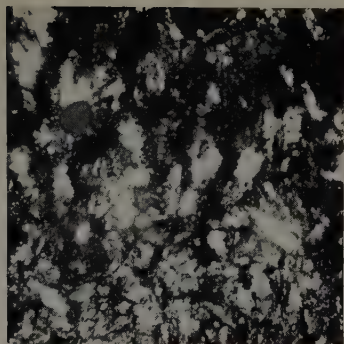
FIG. 37.—Junction between Zones *A* and *B*. Tridymite crystals in upper portion and cristobalite in lower part of section. Between crossed nicols. × 50.
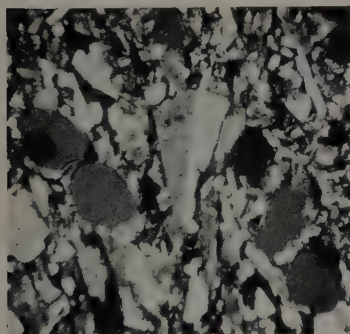
FIG. 38.—Large Tridymite Crystals in Zone *B*. Between crossed nicols. × 50.
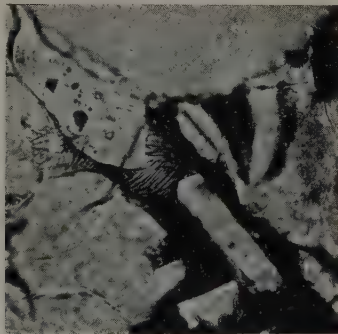
FIG. 39.—Lamellar Eutectic of Mellorite and Tridymite from Zone *C*. Ordinary light. × 500.
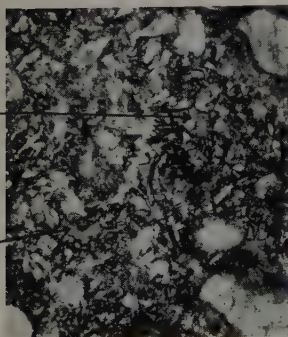
FIG. 40.—Yellow Glass in Patches from Zone *E*, indicated by arrows. Ordinary light. × 50.
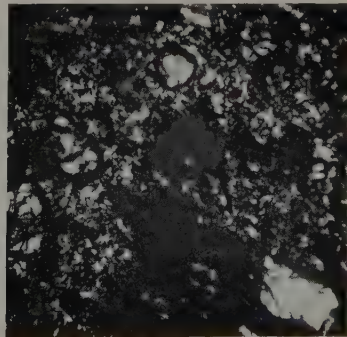
FIG. 41.—Zone *F*; tridymite crystals in glassy matrix. Quartz grain at lower right-hand corner. Crossed nicols. × 50.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Basic O.H. Roofs, Section VI.*

PLATE XXVIII.
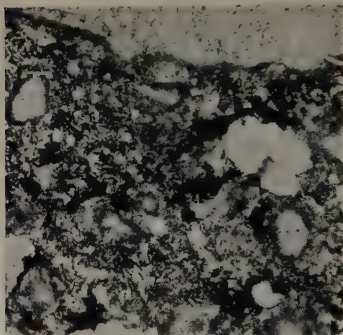
Fig. 42.—Aggregations of Hematite in Zone G. Ordinary light. × 50.
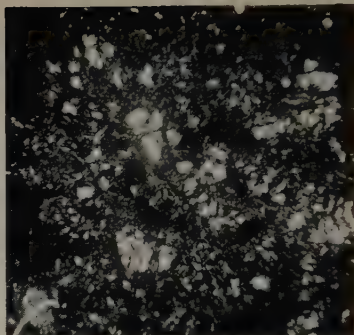
Fig. 43.—Large Fragment of Ganister from Zone H, partly changed to tridymite. Crossed nicols. × 50.
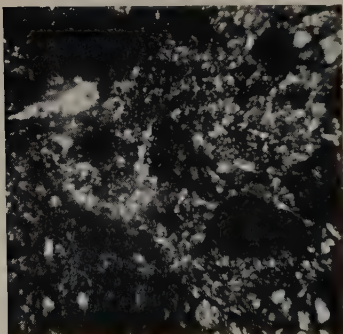
Fig. 44.—Matrix from Zone H; well-developed tridymite. Crossed nicols. × 50.
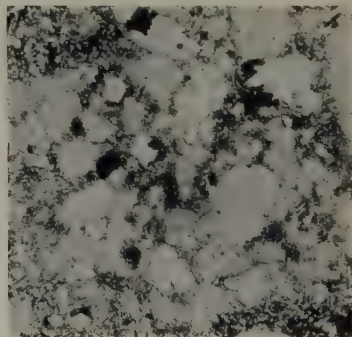
Fig. 45.—Aggregations of Ferruginous Matter in Zone I. Ordinary light. × 50.
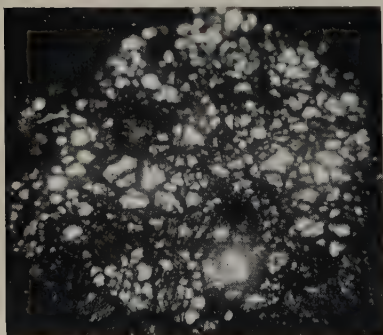
Fig. 46.—Large Ganister Fragment in Zone J; mainly unchanged quartz. Crossed nicols. × 50.
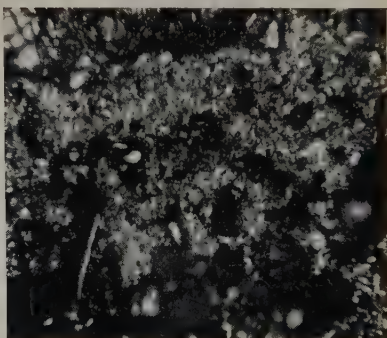
Fig. 47.—Matrix in Zone J; development of tridymite. Crossed nicols. × 50.

(Micrographs reduced to two-thirds linear in reproduction.)

carried towards the cold end of the brick, eventually becoming concentrated in a zone about 20 mm. deep and pale yellow in colour (zone F), where it remains as a glass. Its place is taken by the mellorite-tridymite eutectic as a crystalline substance in fine lamellæ as far as zone D, similar in structure to that shown in Fig. 39. In zone E this eutectic occurs but is not capable of crystallising. The temperature of zone E on the upper curve of Fig. 20 varies from 1160° C., where it joins D, to 1140° C., where it joins zone F. Hence, point Z on the curve for the maximum temperature attained—that is, the upper curve in Fig. 20—becomes important as a factor limiting the position of this eutectic. This is also the limit to which lime and iron oxide, &c., from the furnace reach within the brick. The matrix at this zone consists almost entirely of an orange-yellow glass of high refractive index. Patches of this glass are indicated by arrows in Fig. 40. When separated from the brick it was contaminated with small amounts of quartz. Melts made with decreasing silica contents until a glass of the same optical properties was obtained had the following composition : SiO_2, 56·03%; TiO_2, 1·02%; Al_2O_3, 5·09%; Fe_2O_3, 16·98%; CaO, 17·32%; MgO, 1·36%; MnO, 0·34%. This corresponds with a mixture of 68·5% mellorite and 31·5% silica. Mellorite has the following composition : SiO_2, 38·58%; TiO_2, 0·76%; Al_2O_3, 7·84%; FeO, 3·45%; Fe_2O_3, 21·57%; CaO, 24·67%; MgO; 2·67%; MnO, 0·79%. While similar to orthorhombic pyroxenes in its optical properties, it has a molecular formula closely allied to the garnets, $viz.$ 2·7 R''O, R'''$_2$O$_3$, 3·08 R''''O$_2$. Holmquist,[3] in a study of used silica bricks from the roofs of furnaces at Sandviken, found crystallised garnet (melanite) at this zone. Melanite is intermediate between grossularite $(3CaO.Al_2O_3.3SiO_2)$ and andradite $(3CaO.Fe_2O_3.3SiO_2)$. He states that this garnet is stable up to its melting point, but garnets are usually found in nature where rocks have been subjected to considerable stress and are not readily prepared by dry fusion. This mode of occurrence of garnets has recently been reiterated by Flint, McMurdie and Wells,[4] in their study of the garnet-hydrogarnet series. It may be that stresses sometimes occur in roof bricks which are sufficient to facilitate the formation of garnets, but at the present time the magnitude of such stress is not known.

(c) The third factor contributing to the formation of zones, $viz.$, the passage of furnace gases through the brick, now requires consideration. One of the noticeable features of the analyses of the back zones of the brick, that is, zones G to J, is the increase in the amount of sulphur compounds remaining in these zones. It appears, therefore, that oxides of sulphur carried in the furnace gases and capable of passing into the brick act upon the glassy matrix, with the liberation of ferric oxide or the formation of ferric sulphate. In zones G and H the temperature is above the stability range of ferric sulphate and hence free ferric oxide is formed. In G this ferric oxide becomes aggregated, thus giving a strong purple colour, while in

zone H it is distributed throughout the matrix as minute crystals of hematite. The effect of temperature on the colour of ferric oxide formed from ferrous sulphate has been studied by Meir and Mellor.[5] It is interesting to note that zone I, which is purple in colour, corresponds closely in temperature with the dissociation temperature of ferric sulphate (670° C.).[6] The result of the repeated formation and decomposition of ferric sulphate at this zone is the formation of aggregates similar in character to, but somewhat finer in texture than, those formed in zone G. The sulphur content calculated as sulphur trioxide is 0·61 % in this zone. The sulphur trioxide (0·76%) in zone J is probably present as ferric sulphate, because the temperature has not exceeded 670° C.

·Conclusions.

(1) The transformations of the free silica in these roof bricks agree with the results of previous investigations on the stability of the various forms of silica.

(2) A complex lime/ferric-oxide silicate (mellorite) is produced and this forms a eutectic with excess silica. This eutectic melts at a low temperature (about 1160° C.) and is therefore a factor of considerable importance in the life of roof bricks.

(3) Furnace gases can pass through the brick, and sulphur compounds in these gases attack the glassy matrix, with the formation of either ferric oxide or ferric sulphate, depending on the temperature.

REFERENCES (SECTION VI.).

(1) R. B. SOSMAN and J. C. HOSTETTER : *Transactions of the American Institute of Mining Engineers*, 1917, vol. 58, p. 409.

(2) The crystalline substance "mellorite" was described by W. HUGILL in *Bulletin of the British Refractories Research Association*, 1939, No. 49, p. 15.

(3) F. J. HOLMQUIST : *Geologiska föreningens i Stockholm förhandlingar*, 1925, vol. 47, p. 215.

(4) E. P. FLINT, H. F. McMURDIE and L. S. WELLS : *Bureau of Standards Journal of Research*, 1941, vol. 26, p. 32.

(5) G. E. MEIR and J. W. MELLOR : *Transactions of the Ceramic Society*, 1937, vol. 36, p. 31.

(6) F. H. CLEWS, N. E. DOBBINS and A. T. GREEN: *Gas Research Board, Thirty-First Report of the Refractory Materials Joint Committee*, 1940, p. 104.

Section VII.—General Conclusions.

(a) *The Raw Materials, and Manufacture of Silica Bricks.*

There is a present trend in favour of dense silica bricks for open-hearth roof construction, but the minimum porosity which can be attained is limited by the nature of the quartzite. The porosity of the quartzite used in the present work increased from 1 % or less

before firing to about 10% after firing; this feature of the raw material sets a lower limit to the porosity of the fired brick. It has been found that comparatively large quartz pebbles may be converted more rapidly than fine-grained rock of the normal type; X-ray studies have shown that this is a result of strain in the crystal lattice. X-ray investigations also suggest that, while there may be no obvious relation between the fineness of grinding and the rate of conversion, the more finely ground fraction yields a greater proportion of tridymite in the conversion product.

(b) *Methods of Roof Construction.*

The use of $\frac{1}{8}$-in. felts in alternate cross joints was successful in giving adequate space for expansion. A bad feature of the bonded roof was very clearly illustrated, *viz.*, the slipping-through of odd bricks as a result of local unevenness. This is very difficult to avoid, even with new skewback channels and bricks of good shape and size; with straight rings, this fault does not arise. However, the sharing of the load in a bonded roof is advantageous during the later stages in the campaign, when parts of the roof have worn thin.

(c) *Roof Pyrometry.*

The radiation-type pyrometer focused through the back wall is well adapted to recording the temperature of an open-hearth furnace roof. It is essential that an air jet be used in conjunction with the radiation pyrometer in order to keep the lens clean, and the instrument must be calibrated at regular intervals.

(d) *Warming-up Open-Hearth Furnaces.*

Gas flares enable the roof of an open-hearth furnace to be warmed up steadily to a temperature above the critical spalling range of silica bricks. It is normal practice to warm up a furnace with the valve on centre and the stack damper down. On opening the stack damper the rush of cold air into the furnace causes a serious drop in the surface temperature of the roof; in the present case the inner face of the roof fell from 600° C. to 350° C. within a few minutes. This violent drop in temperature on opening the stack damper has been observed elsewhere, and calls for a modification in practice. It may be noted that a considerable improvement has been achieved since this work was carried out, by building a fire at the base of the stack and subsequently opening the damper gradually and as late as possible. A further observation made during the initial warming-up period was that the roof at the ends of the furnace was 100° C. colder than at the centre; this difference might be eliminated by adjustment of the flares and the furnace doors.

(e) *Shut-Down Periods.*

On taking the gas out of an open-hearth furnace, the temperature of the inner face of the roof falls so rapidly that within a few minutes

it is cooler than the centre of the brick.   When small repairs are in progress and the doors of the furnace are left open, the inner face of the roof continues to cool steadily.   Immediately the doors are closed on completing the repair, however, the temperature of the inner roof begins to rise as a result of radiation from the bath and walls and conduction from the middle of the brick.   Normally the hot-face temperature never falls below 500–600° C.   During a more lengthy shut-down, the temperature of the inner face was 315° C. after five days ; this was still above the critical spalling range for the cristobalite zone at the face of the brickwork, but on opening the stack damper prior to gassing, the temperature fell to 180° C.   This observation emphasises the extreme importance of stack-damper adjustment when the furnace is off gas.

Spalling was not observed on any occasion.   The most rapid heating-up (after a repair to the bottom) involved gassing the furnace after only 6 hr. preliminary warming.   On this occasion a crack opened along the apex of the roof, owing to the sudden lifting of the arch ; hence rapid heating may lead to reduced roof life, even when no spalling is apparent.

(f) *Temperature Fluctuations during a Single Heat.*

On tapping and recharging an open-hearth furnace, the temperature of the inner surface of the roof falls 300–400° C. very rapidly. This severe temperature drop affects the front $\frac{1}{2}$ in. of the brickwork almost instantaneously, but 3 in. back there is a time lag of about $\frac{1}{2}$ hr.   Temperature fluctuations amounting to 200° C. also occur throughout the charging period ;   these follow the individual charging operations in a quantitative manner.   It would appear probable that these severe temperature fluctuations, which must reduce the rate of output in addition to introducing stresses in the furnace structure, could be somewhat levelled out by adjusting the sequence and spacing of the charging operation.

In addition to the violent changes in the roof temperature on tapping and charging, fluctuations of about 50° C. occur on each reversal.   Since the thermocouple $\frac{1}{2}$ in. from the working face also recorded a corresponding, though smaller, drop in temperature on reversing (20° C.), it is concluded that the inner surface of the roof does actually cool slightly during the few seconds while the gas is out of the furnace.

(g) *Progressive Change in the Temperature Gradient.*

As the campaign progressed the temperature within the body of the roof increased at a fairly regular rate, owing to wear of the brickwork and, possibly, an increase in its thermal conductivity. Towards the end of the campaign the furnace became slightly out of balance, the roof temperature being 20–30° C. hotter while the gas was entering from one end.

(h) " *Seasoning.*"

The change in temperature gradient just noted was most marked during the first two weeks of the campaign; the most significant feature of this change was the increased conductivity of the cristobalite zone at the hot end of the brick. This suggests that one important effect of seasoning is the elimination of the sudden drop in temperature at the hot face of a new roof. The temperature gradient alters its course at the junction of the cristobalite and tridymite zones, so that the crystallisation of cristobalite at the hot face of a roof may be considered to be an essential feature of seasoning.

Other important features of seasoning appear to be a marked decrease in porosity and an increase in refractoriness.

(i) *Temperature Variation in the Roof at Different Positions in the Furnace.*

During the first two months the centre of the roof was hotter than either the tapping or the charging side. During the third month there was a sudden increase in temperature at the tapping side; this was associated with a period of rapid wear along the back of the roof and is attributed to wear of the ports followed by poor flame control.

(j) *The Nature of the Dust in the Furnace Atmosphere.*

Under the operating conditions at this plant, the amount of dust contained in the furnace atmosphere was about five times as great during the charging period as during melting and refining. The dust during charging consisted largely of lime, but during melting iron oxide preponderated. The actual weight of iron oxide deposited per unit time was approximately constant, which may be taken as additional evidence that this oxide is present in the furnace atmosphere as vapour. When using mixed scrap, as in the present case, considerable amounts of non-ferrous metals may be introduced into the charge. Of these, lead and zinc are perhaps the most important; the zinc oxide is the less volatile and condenses in the checkers, while the lead oxide concentrates in the flues. It has been shown elsewhere that zinc oxide may cause serious slagging in the regenerator chambers, but none of the non-ferrous metals appears to be responsible for the wear of refractories above the stage level; the last statement excludes the collection of metallic lead sometimes encountered below the hearth.

(k) *The Absorption of Fluxes by the Roof.*

The zoned appearance of the used roof bricks followed normal lines, but certain important new features were noted during the laboratory work. The iron-oxide content of the cristobalite zone was somewhat higher than that of the tridymite zone, contrary to the findings of many previous investigators. The lime was found to have concentrated a little nearer to the hot face than the pale yellow zone usually assigned to it. The refractoriness of this calcareous

zone was 1685° C. for a cut specimen and 1640° C. for a powdered specimen; the permeability of this zone was almost zero, owing to the presence of a continuous narrow band of glass. This glass, detected by microscopical and confirmed by X-ray studies, appears to be a eutectic of mellorite (a complex lime/ferric-oxide silicate) and excess silica; this eutectic melts at a low temperature (about 1160° C.) and is therefore a factor of considerable importance in the life of the roof. Furthermore, in several samples a crack coincident with this band of glass was observed running through the brick.

Furnace gases can pass through the brick, and analysis has shown a concentration of sulphur compounds at the cooler end of the roof bricks; interaction between the sulphurous gases and the iron oxide present in the brick may give rise to several pink, red or purple zones.

(1) *The Effect of " Foaming."*

During a period of close observation when a charge was foaming badly, it was found that the surface temperature of the roof reached 1760° C. for a few minutes; the bricks dripped during this short period of intense heat. The temperature record and observations during this stage confirm the widely-held view that considerable damage may be caused to the refractories by the intense heat associated with foaming.

CORRESPONDENCE.

Dr. JAMES WHITE (The Royal Technical College, Glasgow) wrote that the phenomena associated with the deterioration of basic open-hearth roofs were undoubtedly complex, and the authors were to be commended for having made a serious attempt to record and correlate all factors contributing to the changes occurring in the particular roof studied. Their conclusions as to the manner in which the various fluxes were carried in the furnace atmosphere were substantially the same as those reached during a study of pocket slags at the Royal Technical College a few years ago. Comparison of the $P_2O_5 : CaO$ ratio in the furnace slag and in the slagging product indicated that little furnace slag as such was carried in the gases. CaO was carried mainly as dust during charging and feeding of lime, and the use of limestone as distinct from lime was found to diminish noticeably the CaO content of the slag formed in the downtakes. Fe_2O_3, on the other hand, was found to have an appreciable vapour pressure at steelmaking temperatures, as was shown by the fact that a stream of air or oxygen passed over the molten oxide caused a permanent loss of weight. In another series of experiments it was found possible to collect a detectable amount of the vaporised oxide by drawing the gas through an asbestos-wool plug after it had passed over the oxide. This meant that, even if all possible precautions were taken to avoid the feeding of fine, dusty ore or scale, iron oxide would still find its way to the roof, ports, downtakes, &c.

The authors' findings with regard to the penetration and zoning that occurred following the deposition on the roof bricks of these gas-borne fluxes were substantially in agreement with those of previous workers. Two of the present authors (Mr. Dodd and Mr. Green [1]) ascribed the effects observed mainly to capillarity. Capillarity would almost certainly play a large part in the initial rise of liquid in the pores of the brick, but the regularity of the phenomena associated with zoning suggested that, later, influences giving a closer regulation of the flux distribution were operative. The conception of a liquid phase saturated with SiO_2 and varying in composition with temperature according to phase equilibrium requirements up to the limit of its penetration appeared capable of accounting for the observed relationships. Thus, if the penetration of a single flux, RO, were considered, the composition of the saturated liquid in the brick would vary with temperature along the line AB of Fig. A, if A were assumed to represent the temperature of the hot face and B the temperature at the limit of penetration. As fresh flux deposited at the hot face, the liquid at A would tend to become unsaturated and out of equilibrium with the SiO_2 of the brick, a condition that could be remedied in

[1] First Report on Refractory Materials, p. 21, *Iron and Steel Institute,* 1939, *Special Report No.* 26.

three different ways : (1) By solution of SiO_2 from neighbouring silica grains ; (2) by diffusion of flux into regions where its " activity " was less, *i.e.*, into saturated liquid further away from the hot face ; and (3) by diffusion of SiO_2 outwards towards the hot face from the saturated liquid to the unsaturated. It might be pointed out that (2) and (3) involved the movement of ions, not of molecules, and might well occur with comparable velocity to (1). It was necessary to distinguish between the concentration of the flux in the liquid and its concentration in the brick as a whole. Thus, if (1) predominated the bulk of the liquid and the flux content of the zone as a whole would increase. Reaction (3) would tend to have the same effect. Reaction (2), on the other hand, would tend to give a fairly regular diffusion of flux into the brick *via* the liquid phase and a regular distribution of saturated liquid throughout the
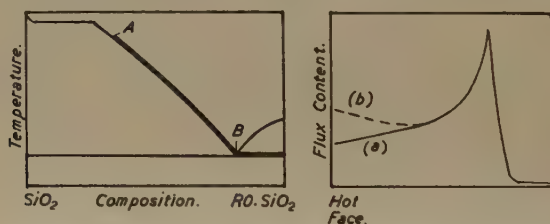
FIG. A.—Suggested Relationship between Composition of Saturated Liquid Phase and Flux Content.

brick, so that a regular increase in the flux content of the brick, corresponding to the increase in the flux concentration in the liquid phase, would tend to occur behind the hot face. It was generally accepted that flux penetration ceased at the temperature of the flux-SiO_2 eutectic. At this temperature a phase richer in flux than the SiO_2-saturated liquid ($RO.SiO_2$ in Fig. A) could co-exist in equilibrium with SiO_2. Hence, as flux diffused inwards to this zone, this compound would tend to separate in increasing amounts, causing an increase in the flux content of the brick at this critical point. The flux concentration curve resulting, assuming reaction (2) to predominate, would have the form shown in Fig. A, curve (*a*). Curve (*b*) showed the effect of reaction (1) predominating in the region of the hot face. This conception was as readily applicable to the penetration of several fluxes simultaneously. In this case the maxima on the various flux concentration curves need not necessarily coincide, as maximum concentration of the different fluxes might correspond to different eutectics (binary, ternary, &c.) of the polycomponent system. Certain departures from these relationships might, of course, arise from, for instance, differences in the thermo-kinetic properties of the different ions or molecules involved, but such effects would probably at most modify, without actually supplanting, the suggested mechanism.

At the hot face of the brick, the limiting flux content was reached when the mass became sufficiently fluid to run and drip at steel-furnace temperatures, and any assessment of the factors affecting the durability of roof bricks must necessarily take into account the contribution of the various fluxes towards the attainment of this condition. One of the difficulties associated with this question lay in the uncertainty that existed as to the state of oxidation of the iron oxide in the brick at the furnace temperature. The authors were at some pains to record ferrous- and ferric-oxide contents (or ferrous/ferric ratios) in the different zones. These were undoubtedly of some significance as regarded their variation
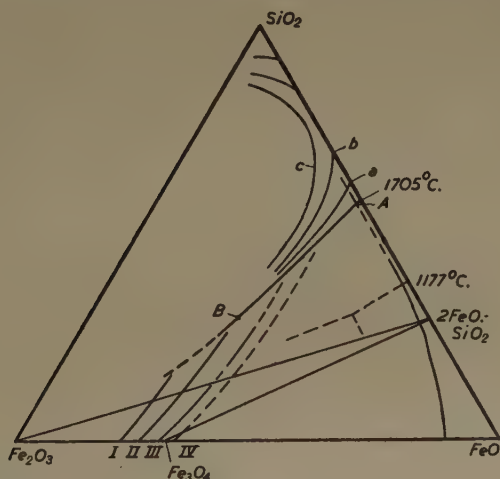
FIG. B.—System FeO–Fe_2O_3–SiO_2. *I., II., III., IV.* : Curves showing FeO and Fe_2O_3 contents of iron-oxide/SiO_2 melts at 1619° C. at oxygen pressures of 76, 15·2, 4 and 1 cm. of mercury. *AB* : Curve of SiO_2-saturation at biliquidal temperatures. *a, b, c* : Limits of biliquidal zone with 1, 2 and 3% of Al_2O_3.

from zone to zone (arising from the fact that oxidation during cooling of the roof had not been sufficient to mask completely the differences existing at high temperatures), yet, for the hotter zones at least, the state of oxidation so recorded would certainly vary considerably from that existing at high temperatures. Sosman [1] assumed tentatively, for the purposes of computation, that there would be about 10% of Fe_2O_3 in a SiO_2-saturated iron-oxide/SiO_2 melt at steelmaking temperature. It was possible to arrive at a somewhat closer estimate from the present writer's data on equilibrium in iron-oxide melts [2] from which curves I., II., III. and IV.

[1] *Journal of the American Ceramic Society*, 1938, vol. 21, p. 37.

[2] White, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1938, vol. 27, p. 1.

of Fig. B had been derived.   These showed how the ferrous- and ferric-oxide contents of iron-oxide/SiO_2 melts at 1619° C. varied with silica content at oxygen pressures of 76, 15·2, 4 and 1 cm. of mercury, respectively.   (It had been necessary to extrapolate the experimental data to a certain extent, as indicated by the "broken" portions of the curves.)   Curve AB was the SiO_2 saturation curve at the temperature of immiscible-liquid formation in the system FeO–Fe_2O_3–SiO_2 according to Greig,[1] the temperature along AB varying from 1705° C. at A to 1675° C. at B (these figures were according to a revision of Greig's original temperature scale by Sosman, *loc. cit.*).   It was known that the liquidus surface sloped very steeply from AB, so that the saturation limits at 1619° C. would not differ much from those indicated by AB.   Incidentally, Greig's determination of the point B agreed well with the present writer's finding that the saturation limit along curve II. lay between 26·1 and 28·1% of SiO_2.   Now, according to the data contained in The Iron and Steel Institute "Symposium on Steel-making,"[2] the air/gas ratio in normal open-hearth practice was generally such that the oxygen content of the gases after complete combustion would be of the order of 5–6%, corresponding to an oxygen pressure of roughly 4–5 cm. of mercury.   From Fig. B this would give about 25% of Fe_2O_3 and 35% of FeO in a SiO_2-saturated melt at 1619° C.   At the actual hot face the temperature was somewhat higher than this, which would displace the composition somewhat to the right.   On the other hand, since the design of the open-hearth furnace was generally such that a layer rich in air was interposed between the flame and the roof, the estimate of 4–5 cm. of pressure was quite likely a low one.   A reasonable estimate would be that in most furnaces the Fe_2O_3 content would be between 10 and 20% of the saturated melt (probably nearer the latter figure), corresponding to a FeO : Fe_2O_3 ratio of between 4 : 1 and 2 : 1 approximately.   The very lowest figure that it could ever attain with the furnace full of air would be that represented by the point B, which corresponded to a ratio of about 1 : 1.   The particular significance associated with the Fe_2O_3 content in the vicinity of the hot face lay in the fact that, though it lowered the temperature of immiscible-liquid formation from 1705° C. at A to 1675° C. at B, it was unique in that it caused a marked widening of the immiscibility zone, the SiO_2 content at saturation changing from 58% to 31·6% between these points.   Thus, a brick containing 7·59% of iron oxide, all as FeO (*see* analysis of zone 1, Table XVI.), would, just below 1705° C., contain 18·0% of saturated liquid; with 6·17% of FeO and 1·58% of Fe_2O_3 (corresponding to 10% of Fe_2O_3 in the saturated liquid) it would contain 15·8% of liquid just below 1696° C.; and with 5·06% of FeO and 2·80% of Fe_2O_3 (corresponding to 20% of Fe_2O_3

[1] *American Journal of Science*, 1927, vol. 14, p. 473.
[2] *Iron and Steel Institute*, 1938, *Special Report No.* 22.

in the saturated liquid) it would contain 14·0% of liquid just below 1687° C. If liquid of composition B should be formed the brick would have only 11·7% of liquid when on the point of complete liquefaction. The importance attaching to the amount of the liquid phase formed was shown by the destructive effect which a reducing atmosphere had on SiO_2 bricks containing iron oxide, though it was, of course, possible that a decreasing viscosity with decreasing Fe_2O_3 content might partly account for this.

The above estimates were based on the iron-oxide content only, and the amounts of liquid indicated would be considerably lower than was actually the case in the bricks examined. The contribution made in the presence of the iron oxide by the 3·46% of CaO found in zone 1 could be estimated, at least approximately, from the effect of CaO on the FeO–SiO_2 biliquidal range,[1] if it were assumed that in the quaternary system (see Fig. C) the surface of
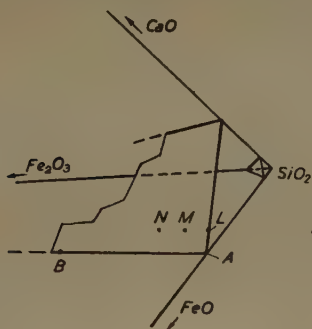
FIG. C.—Sketch of a Portion of the Surface of SiO_2-saturation at temperature of immiscible liquid formation in the quaternary system CaO–FeO–Fe_2O_3–SiO_2.

SiO_2-saturation at the biliquidal temperature was approximately plane over the somewhat restricted range involved and that the temperature also varied linearly over this range. Thus, a brick with 7·59% of FeO and 3·46% of CaO (point L) would have 29·4% of liquid just below 1708° C.; with 1·58% of Fe_2O_3 formed by oxidation of the FeO (point M) it would have 26·4% of liquid just below 1702° C.; and with 2·61% of Fe_2O_3 (point N) it would contain 23·9% of liquid just below 1695° C. The other fluxes would raise these figures still further. In particular, Al_2O_3, by virtue of its drastic action in removing the immiscibility in silicate melts, would have an effect out of all proportion to the smallness of the amount present. Thus, less than 3% of Al_2O_3 completely eliminated the immiscibility in CaO–SiO_2 melts (first causing the biliquidal temperature to drop by about 20° C.) and FeO–SiO_2 melts. Curves

[1] Bowen, Schairer and Posnjak, *American Journal of Science*, 1933, vol. 26, p. 193.

(a), (b) and (c) of Fig. B showed the effects of 1%, 2% and 3% of Al_2O_3 on the immiscibility zone of the system $FeO–Fe_2O_3–SiO_2$ according to Greig. The effect was such that 1% added to a brick containing 7·59% of FeO would increase the amount of liquid formed below the biliquidal temperature by over 2% of the weight of the brick, while 2% would raise it by over 7%. In this connection it was not without significance that the stalactite analysis given on p. 241 P showed 0·51% of Al_2O_3, as against 0·29% in zone 1. With increasing Fe_2O_3 content, however, this effect of Al_2O_3 was reduced considerably, as shown, which gave another indication of the importance attached to the state of oxidation of the iron oxide at high temperatures. It was not possible to make more than a rough estimate of the contribution of the remaining fluxes, but if the total percentage of the fluxes other than CaO and iron oxides were added to the estimates based on these latter oxides alone, one obtained 31·4%, 28·4% and 25·9% as the amounts of liquid formed immediately before complete melting for the three states of oxidation of the iron oxide previously considered. If it were assumed that these additional fluxes were responsible for the fluxing of an equal weight of SiO_2 (a somewhat conservative estimate) these figures became 33·4%, 30·6% and 27·9%.

With regard to the probable temperature of complete liquefaction, Sosman stated that actual observations placed the fusion temperature of roof bricks at 1650 ± 10° C., this being 30–40° C. lower than was indicated by a consideration of the temperature variation along AB of Fig. B due to the presence of the other fluxes. According to the estimate made above on the basis of the iron oxide and CaO contents, a liquefaction temperature of about 1695° C. was indicated. Of the other fluxes reported, both MnO and MgO formed ranges of liquid immiscibility with SiO_2, and should not lower the liquefaction temperature to any marked extent (MgO should actually tend to raise it somewhat); 0·29% of Al_2O_3 would, however, on the basis of Greig's data, probably cause a lowering of about 3° C., while the remaining 0·98% of fluxes, if equivalent to Al_2O_3 in effect, would cause a further lowering of about 10° C. If they were equivalent to the alkalis the lowering would be about 28° C., a maximum figure. Perhaps a reasonable estimate for the effect of all the fluxes reported would be between 15° and 20° C., or between 15° and 25° C. allowing for possible traces of alkali not reported in the analyses. This would give a final figure for the temperature of liquefaction of between 1670° and 1680° C. In considering possible reasons for the discrepancy between this estimate and the authors' observations, the following points might be raised. First, with regard to their refractoriness tests, (1) subsidence would depend on the formation of a critical volume of liquid, this volume depending on the viscosity of the liquid; (2) with a rising temperature there was liable to be an appreciable time lag due to poor thermal conductivity

of the test and to the time taken for the occurrence of the fusion and solution processes on which the liquid formation depended, and powdering, by speeding-up the latter processes, would be at least partly responsible for the effect described on p. 242 P; (3) the state of oxidation of the iron oxide would probably not be the same during the test as when the material was in the furnace roof. Secondly, with regard to the observations on the roof temperature at the hot face, it was to be noted that only the surface temperature, as recorded optically, reached 1700° C. or over. Accepting these readings as correct, it could yet be seen from the temperature gradients shown in Fig. 11 that only about $\frac{1}{8}$-in. layer of the brick would be over 1675° C. even after " seasoning " had occurred. It seemed quite feasible that a fully liquid but viscous layer of this thickness might be formed in the furnace.

It was also of interest to consider the authors' observations relating to the constitution of the various zones, in the light of our knowledge of the systems involved. According to the phase distribution in the system $CaO–FeO–Fe_2O_3–SiO_2$ as suggested by Hay and White,[1] SiO_2-saturated slags of this system having a $CaO : FeO$ ratio greater than about 1 : 4 would consist, after freezing, of SiO_2, iron-wollastonite solid solution and Fe_2O_3. With ratios lower than this the phases would be SiO_2, $2FeO.SiO_2$, iron-wollastonite and Fe_2O_3. Even with the higher ratios, the separation of pseudo-wollastonite above 1150° C. (its lower limit of stability) could result in the presence of $2FeO.SiO_2$, as pseudo-wollastonite did not form solid solutions containing FeO. Both wollastonite and pseudo-wollastonite had been reported in the literature, as had fayalite. A discrepancy arose, however, in that Fe_3O_4 had several times been reported, whereas with the phase distribution indicated this would be impossible in the case of melts saturated with silica. Consideration of the solidification of a SiO_2-saturated $FeO–Fe_2O_3–SiO_2$ melt in accordance with the relationships indicated in Fig. B would perhaps make this clear. As the phase distribution shown in this latter diagram was fairly well attested, it would appear that in regions where Fe_3O_4 was found the liquid phase might not have been saturated and that the composition lay in the field $Fe_2O_3–Fe_3O_4–SiO_2$ of Fig. B. Such a degree of unsaturation would only seem possible close to the hot face. It might further be noted that no separation of Fe_2O_3 as a distinct species could occur above about 1320° C. at an oxygen pressure of 4 cm. of mercury (about 1360° C. in air).[2] At that temperature the crystallisation of a solid solution of Fe_3O_4 in Fe_2O_3 could begin, and it was perhaps not without significance that mellorite, the new mineral the identification of which was claimed,

[1] *Journal of the West of Scotland Iron and Steel Institute*, 1939–40, vol. 47, p. 87.

[2] White, Graham and Hay, *Journal of the Iron and Steel Institute*, 1935, No. I., p. 91.

first appeared in quantity in zone C (Section VI.), the temperature of which would be of this order.

Two other points might be raised. With regard to Mr. Hugill's suggestion concerning the movement of tridymite grains from zones B, C and D into zone A, were the observations not as well explained from the progressive shift of the zones consequent on the fluxing of the hot face, as a consequence of which zone A would, early in the campaign, be largely in zone B? Secondly, with regard to Fig. 32, the occurrence of uncombined FeO (wüstite) in the presence of so much silica indicated a departure from equilibrium that was most unlikely.

AUTHORS' REPLIES.

Mr. W. HUGILL, in reply, thanked Dr. White for his very interesting contribution on the basis of equilibrium studies in the system $CaO-FeO-Fe_2O_3-SiO_2$. It was clear from actual observation, however, that the intake of iron oxide, lime, &c., did not allow equilibrium to be attained. A certain proportion of the lime and oxides of iron which collected at the hot face was taken up by the brick, at first mainly by capillarity and later mainly by diffusion; it must be remembered, however, that there was also a tendency for a current of liquid to flow out of the brick. This current might at times take a definite direction, as could be seen from Fig. 31 of the paper, in which a slightly darker area extended from the lowest part of zone C and inclined to the right through zones B and A. It was in this stream, where it passed through zone A, that the section shown in Fig. 36 was cut. If Fig. 38 was compared with this, it would be seen that the large tridymite crystals in the latter tended to be orientated with their trilling axis in the plane of the section—that was, perpendicular to the hot face. In Fig. 36, however, these crystals had turned through a right angle; the trilling axis was now perpendicular to the section, and therefore parallel to the hot face. This rotation strongly suggested that these crystals had actually flowed in the runner, rather than that the brick had merely worn back and exposed the crystals.

With regard to Dr. White's remark that the state of oxidation of the iron in the cold bricks might differ from that at working temperatures, this had already been emphasised by the authors (*see* p. 240 P). Such oxidation was probably the cause of the formation of martite close to the hot face, as shown in Fig. 35, due to oxidation of the magnetite crystals on cooling. It was noted that Dr. White considered that, from the standpoint of equilibrium requirements, magnetite should not occur in zone A. This deduction was contrary to Mr. Hugill's own and previous observations. The question of the stability of ferric oxide at high temperatures would depend to some extent on whether it was combined or free.

When ferric oxide was combined with lime, silica and alumina, as in mellorite, it appeared to be stable up to a temperature of at least 1450° C. In fact, this mineral was first found in well-developed crystals in silica bricks which had been exposed to a slag at this temperature. Ferrous oxide apparently had a greater affinity for ferric oxide than for silica; this might account for the prevalence of wüstite solid solution (ferrous oxide containing some ferric oxide) in zones A and B instead of fayalite. It was worthy of note that the latter mineral was not common among those usually occurring in rocks, nor was it readily synthesised in the laboratory.

Dr. J. H. CHESTERS and Mr. T. W. HOWIE wished to be associated with Mr. Hugill in his thanks to Dr. White for his excellent contribution to the discussion. His comments on the possible causes of the high melting points obtained on cones cut from the working face of used roof bricks were most helpful. They would agree that a critical volume of liquid would have to be formed in the cone before subsidence occurred, and that there was bound to be some time lag. Their observations both of the condition of the used roof brick (and, in particular, the rounded pores in the working face) and of the behaviour of the bricks when above the maximum safe temperature supported the suggestion that the first $\frac{1}{8}$ in. and sometimes the first $\frac{1}{2}$ in. was in a pasty condition. Thus, " silicicles " or " stringers " forming on the roof often drew out to lengths of a foot or more before breaking off. This suggested the presence of a layer of very viscous material.
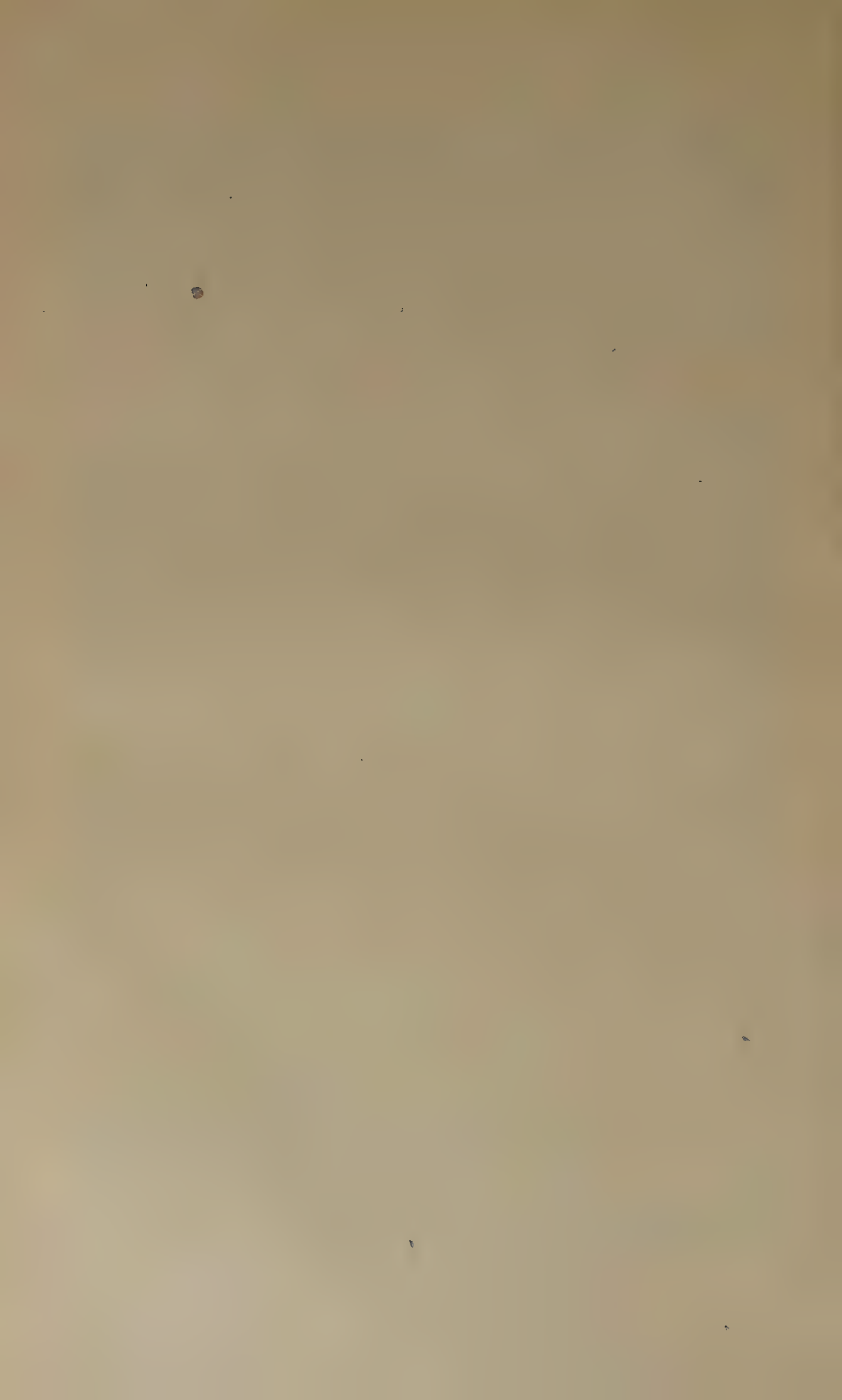
AN X-RAY INVESTIGATION OF IRON-NICKEL-CHROMIUM ALLOYS.*

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SYNOPSIS.

X-ray powder photographs of iron-nickel-chromium alloys were taken in a 9-cm. camera using chromium radiation, the powders being slowly cooled down to room temperature. The positions of the phase boundaries on the constitutional diagram were estimated from the relative amounts of the different constituents present. Four single-phase fields were found, a, body-centred cubic (iron-rich), a', body-centred cubic (chromium-rich), γ, face-centred cubic (nickel-rich), and σ, complex structure (corresponding to the compound FeCr). The two-phase fields are $a + \gamma$, $a' + \gamma$, $a + \sigma$, $a' + \sigma$, $\gamma + \sigma$, and the three-phase triangles are $a + \gamma + \sigma$ and $a' + \gamma + \sigma$. The results therefore confirm the diagram proposed by Schafmeister and Ergang, but the positions of the boundaries of the phase fields are different, showing that alloys in many parts of the system are extremely susceptible to heat treatment at low temperatures.

The addition of nickel to the iron-chromium alloys greatly increases the range of the σ phase. Whereas in the binary system it is practically confined to the exact composition FeCr, in the ternary system it extends from about 45 to 60% of chromium and up to about 6% of nickel.

THOUGH the ternary alloys of iron, nickel and chromium have been the subject of numerous investigations, primarily on account of their important magnetic, mechanical and corrosion-resisting properties, until recently no phase diagram had been drawn for all ranges of composition. This is not surprising in view of the uncertainties still remaining in the three binary systems, the two main difficulties being (a) the sluggish behaviour of the iron-nickel alloys and (b) the doubt as to the formation of a compound FeCr.

Previous investigations have been for the most part concerned with the constitution at high temperatures, giving liquidus and solidus surfaces, with little reference to the transformations which occur in the solid state. For a complete bibliography reference should be made to the outstanding work of Jenkins, Bucknall, Austin and Mellor,[1] who have studied this system as part of their investigation on alloys for use at high temperatures. The work of Bain and Griffiths [2] and of Wever and Jellinghaus [3] is also important. The phase boundaries vary rapidly with temperature, especially in the iron corner of the diagram; this indicates that the alloys are very susceptible to heat treatment.

The object of the present investigation was to obtain a survey of the whole system at a lower temperature than previously, with the intention of constructing a rough map of the phase boundaries, which could be used as the basis of later investigations of the changes which take place in the solid state. The work is therefore of a preliminary character, no attempt being made to attain high accuracy either in composition or in temperature control.

Shortly after this work had been carried out a paper appeared by Schafmeister and Ergang [4] giving a phase diagram for the whole system. They used microscopic, magnetic, X-ray and hardness tests to construct isotherms for 650° and 800° C. after heat treatment for 1000 hr. Combining their results with the earlier work of Wever and Jellinghaus, and Jenkins and his co-workers, Schafmeister and Ergang were enabled to construct a space model showing changes of phase boundaries between 650° C. and the melting points. A tunnel runs in the space model between the σ phase field (FeCr) and the austenitic phase field (γ) on the Fe-Ni side of the diagram. Within this space ($\sigma + \gamma$) alloys are to be found. The tunnel walls are composed of the phase field ($\alpha + \gamma + \sigma$). Over the roof of the tunnel (above 920° C.) only the two-phase field ($\alpha + \gamma$) is to be found.

The present work is in general agreement with Schafmeister and Ergang's results for 650° and 800° C., and therefore confirms the correctness of this model, but the phase boundaries are widely different in many places, showing that the system is very susceptible to heat treatment, especially below 920° C., and will therefore amply repay further study, though very slow cooling and long times of annealing may be required. The present paper is therefore put forward as a further contribution to the study of the system, and in particular to show that the X-ray method alone is perfectly capable of giving all the phase boundaries under the conditions used in these experiments. Schafmeister and Ergang considered that the presence of the σ phase in small quantities could not be detected by this means, but the present work does not confirm this conclusion, since the authors have detected the presence of the σ phase even further towards the Fe–Ni edge of the diagram than they report. In agreement with their results the authors conclude that the ($\sigma + \gamma + \alpha'$) region can be successfully delineated by X-ray methods, whereas Schafmeister and Ergang stated that it could not be detected by microscopic means.

Experimental.

Binary and ternary alloys containing various proportions of iron, nickel and chromium have been prepared in a high-frequency induction furnace under a low pressure of hydrogen. Before solidification the furnace was evacuated. The materials used were Hilger iron No. 8038 and nickel No. 7636 of 99·97% purity and electrolytic chromium from the Electro-Metallurgical Co. of America. The analysis of the latter is as follows :

Chromium.	Iron.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.
99·38%	0·003%	0·02%	0·02%	0·20%	0·488%	0·013%

It is realised that the purity of the chromium is not as high as might be desired (especially with regard to the nitrogen and the oxygen contents), but it compares favourably with that employed by most previous workers.
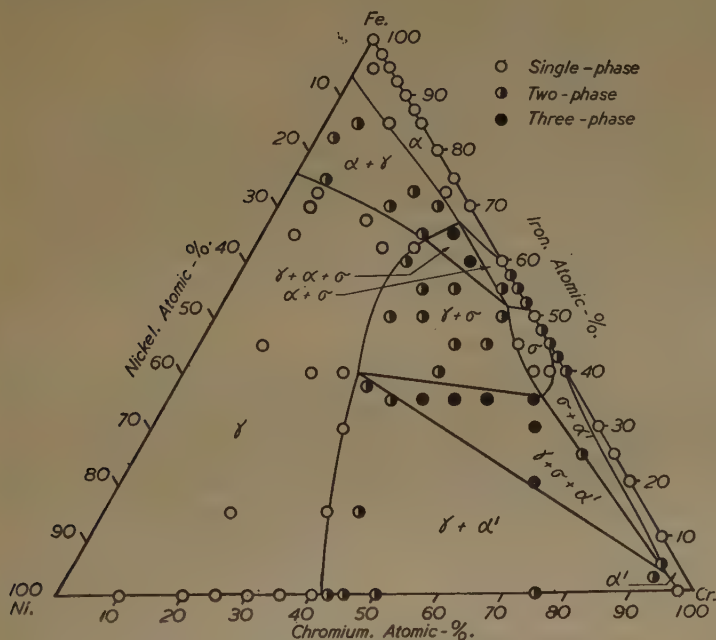
Fig. 1.—The Iron-Nickel-Chromium System.

The melts were made in alumina-lined crucibles; this proved satisfactory in most cases, when the chromium content was not high. Zirconia was occasionally used as a lining for chromium-rich alloys. Ingots of 20 g. were prepared and annealed *in vacuo* for two or three days at temperatures between 1100° and 1300° C. to attain homogeneity. Powders were obtained by filing, and in order to remove the effect of cold-work they were annealed *in vacuo* between 800° and 900° C. The cooling rate was between 20° and 10° C. per hr. Later experiments on iron-nickel alloys show that this rate of cooling allows equilibrium to be followed down to about 650° C. Below this temperature the results are only valid where there are no further transformations. To obtain equilibrium below the next transformation temperature, further annealing is required. The general practice was to lump-anneal at a temperature below 650° C. any

alloys which showed evidence of changes; for this purpose nine days at 570° C. usually gave satisfactory results.

X-ray powder photographs were taken using chromium radiation. Generally the K_β component was not filtered out because the lines were useful for determining lattice spacings. The photographs were examined to ascertain the nature, number and proportions of the different phases, and the results have been used to construct the constitutional diagram, shown in Fig. 1. The lattice spacings were not accurately measured, as chromium radiation is unsatisfactory in the case of face-centred cubic alloys, and manganese radiation was not then available.

The phases have been named in accordance with the nomenclature used by Schafmeister and Ergang : α and α′ are body-centred cubic, α being the iron-rich phase, α′ the chromium-rich phase; γ is the austenitic nickel-rich phase, and σ is the phase FeCr.

The Appendix summarises the experimental results, giving a record of the heat treatments and the phases found from the X-ray powder photographs. The phase diagram (Fig. 1) was directly constructed from these data.

The Iron-Nickel System.

An account of the authors' X-ray work on the iron-nickel system has already been published.[5] The essential feature of the diagram so obtained is that a clearly marked two-phase region (α + γ) is found at about 570° C., between about 6–7% and 23–26% of nickel. With less nickel the alloys are body-centred cubic; with more nickel they are face-centred cubic. For present purposes we are not concerned with the positions of these boundaries at higher or lower temperatures.[6]

The Iron-Chromium System.

Previous investigators disagreed as to whether iron and chromium were completely miscible, forming a continuous series of solid solutions of a body-centred cubic type at all temperatures, or forming a compound FeCr. Table I. gives a summary of the results obtained in recent years, mentioning, where known, the heat treatment and the purity of the chromium.

The survey shows that, if the compound FeCr exists, it is certainly decomposed on heating to 1000° C. The weight of evidence is in favour of its formation at lower temperatures, provided that sufficient time is given, though Adcock's second communication [19] is in contradiction to this conclusion.

The present investigation confirms the existence of FeCr. An alloy of this composition, after being lump-annealed for three days at 1200° C., gave a powder which, on cooling at 10° C. per hr., yielded a characteristic complex powder photograph. The pattern corresponds to a distorted body-centred cubic structure, as the majority of the lines are distributed around positions corresponding

TABLE I.—*Previous Work on Iron-Chromium Alloys.*

Worker.	Method.	Chromium Used.	Heat Treatment.	Result.
Murakami [7]	Magnetic, microscopic	95·92% Cr 0·43% C 2·84% Al 0·45% Si	No special treatment	Continuous solid solution.
Bain [8]	X-rays	?	Rapidly cooled. Long anneal at 1100° C.	Continuous solid solution. Compound forms.
Pakulla and Oberhoffer (with Esser) [9]	Thermal	Aluminothermic (99% Cr)	Examined as cooled from melt (?)	Continuous solid solution.
Pakulla and Oberhoffer (with Esser) [9]	Dilatometric	?	?	No compound. A_2-point falls to room temp. with 75% Cr (not confirmed).
von Vegesack [10]	Microscopic, thermal	Rather impure	3 hr. anneal at 850° C., quench 1050° C.	Continuous solid solution.
Bain [11]	Microscopic	?	Various quenches	Continuous solid solution at high temp., apart from a γ loop which was traced.
Oberhoffer and Esser [12]	X-rays	?	?	
Chevenard [13]	Differential dilatometric for solid transformations	?	?	" Irregularities in expansion of alloys for more than 42% Cr suggests a solid solution up to 40% Cr, then a compound."
Bain and Griffiths [3]	" After sufficiently slow cooling or long annealing below 950° C. a hard, brittle, non-magnetic phase is formed which by heating above this temperature and subsequent quenching disappears again." Observed between 45 and 57% Cr. Also in Fe–Ni–Cr alloys.			
Westgren, Phragmén and Negresco [14]	X-rays	?	No lump-anneal, powder at 1000° C. for some min.	Continuous solid solution.
Kreutzer [15]	X-rays at high temp.	?	?	Continuous solid solution.
Wever and Jellinghaus [3]	X-rays, microscopic (Fe–Ni–Cr and Fe–Cr)	98% Cr 0·86% Fe 0·56% Si 0·01% Al	Anneal 4 days at 600° C.	Compound formed FeCr extent about 30–70% Cr at 500–600° C., disappears by anneal at 1200° C.
Adcock [16]	Thermal, dilatometric	Very pure	Anneals and quenches	Continuous solid solution.
Scheil [17]	Interprets a result of Adcock's (depression of magnetic transformation point on quenching for composition FeCr) as indicating a compound.			
Preston [18]	X-rays (spacings)	As Adcock [16, 19]	Lumps 12 hr. at 1300–1350° C., powders at 1000 C. for few min.	Continuous solid solution.
Adcock [19]	X-rays, microscopic	As above [16]	4 days' anneal at 600° C.	No compound.
Ericksson [20]	X-rays	?	?	Compound FeCr.

to a body-centred cubic lattice. The powder photograph is faintly reminiscent of that given by α-manganese, which is suggestive, in view of the intermediate position of manganese between iron and chromium in the periodic table.

To test whether the formation of FeCr might depend on the presence of impurities, an alloy was made up from electrolytic chromium from the National Physical Laboratory, in which the only impurity was oxygen. Here, too, the σ-phase was observed after the powders had been slowly cooled. The addition of $2·5\%$ of aluminium to an alloy of the exact composition FeCr for the purpose of deoxidation did not modify this result. The formation of this compound is therefore not due to the presence of nitrogen or oxygen in the chromium.

An attempt was made to determine the homogeneity range of FeCr, a complete series of binary alloys being prepared. Only the alloy containing exactly 50 atomic-% of chromium was found to be pure σ, though a number of other alloys contained mixtures of this phase with one or other of the two body-centred cubic lattices. The results are incorporated in the phase diagram.

Some experiments with quenched powders showed that the range of the σ-phase contracts with rising temperature. On quenching from 830° C., an alloy with exactly 50 atomic-% of chromium was no longer pure σ, but also contained some of the body-centred cubic structure; this suggests that FeCr decomposes at about this temperature. This conclusion is confirmed by the decrease in the amount of σ found in neighbouring alloys.

The Nickel-Chromium System.

This system has recently been examined in detail by Jenkins, Bucknall, Austin and Mellor,[1] who give a survey of past work. Though suggestions have sometimes been made that a compound might be formed, it is now agreed that the face-centred solid solution of chromium in nickel and the body-centred solid solution of nickel in chromium are in direct equilibrium with one another. The solubility limits vary according to different observers, possibly on account of impurities in the chromium.

In the present investigation it was found that after slow cooling about 40% of chromium dissolved in nickel, but less than $2·5\%$ of nickel dissolved in chromium. Intensity estimates put the most probable limits at 41 and 99 atomic-% of chromium. These figures are in rough agreement with the values given by Jette, Nordstrom, Queneau and Foote [21] from X-ray work on quenched alloys.

The Ternary Diagram.

The following phase-fields were found :
> Single-phase : α, α′, γ, σ.
> Two-phase : α + γ, α′ + γ, α + σ, γ + σ, α′ + σ.
> Three-phase : α + γ + σ, α′ + γ + σ.

There was no evidence for the formation of a ternary compound.

The γ-Phase.—The face-centred cubic γ-phase field includes the γ-phase of the nickel-iron and nickel-chromium systems, and the ternary γ-phase is stable over a wide range of compositions.   In the iron-nickel alloys about 75% of iron may be present, under the conditions of the authors' experiments, before the face-centred cubic structure breaks down.   The substitution of chromium for nickel at first does little to change this limit, but after the addition of about 20% of chromium, there is a sudden break in the solubility line. From here onwards, it is no longer the iron content, but the chromium content, which determines the limit of solid solubility.   Near the nickel-chromium side of the diagram, the solubility limit is characterised by an almost constant nickel-chromium ratio of about 3 to 2.

The addition of both iron and chromium to nickel produces an increase in the lattice spacing, though chromium is less effective than iron in this respect.   A maximum spacing occurs at about 38% nickel in the iron-nickel system.[22]   There is a corresponding spacing " ridge " in the ternary system, in a direction proceeding from the iron-nickel side towards the chromium corner.

The α-Phase.—The addition of chromium decreases the solubility of nickel in iron at moderate temperatures.   Up to about 25% of chromium, the body-centred cubic phase is in equilibrium with the face-centred cubic nickel-rich phase, but beyond this point it is in equilibrium with the σ-phase, about which more will be said later.

A satisfactory investigation of the α + γ region is of the utmost importance from a practical point of view, since the stainless steels occur in this part of the diagram.   The preliminary results which have been obtained up to date show that the ternary alloys probably behave very similarly to the binary alloys containing rather smaller proportions of nickel, but this conclusion is subject to modification when further experiments are carried out on the ternary alloys, on the lines already established for the binary system.

The general effects of heat treatment are, of course, well-known. The austenitic face-centred cubic structures are favoured by addition of nickel and of chromium, and are formed at high temperatures within the " γ region."   At lower temperatures the face-centred structure tends to break down into the body-centred ferritic structures.   If the decomposition is rapid, a distorted body-centred structure of martensitic type may be obtained.   Prolonged annealing, as the present experiments show, leads to the formation of a definite two-phase structure over a wide range of compositions.

In the ternary system, this process may at higher chromium contents become further complicated by the intervention of the σ-phase, the presence of which is invited by annealing at lower temperatures.   The important rôle played by this phase in the ternary diagram can be gauged by the large areas of single-phase, two-phase and three-phase fields into which it enters.   The results obtained in this part of the system will now be described.

The σ-Phase.—It was most surprising to find that the homogeneity range of the σ-phase was enormously extended by the addition of nickel. At about 3–4% of nickel this phase reaches its widest extent, stretching from about 45 to 60 atomic-% of chromium. The maximum solubility of nickel is about 6%. Since the addition of chromium to iron-nickel alloys still further increases their sluggishness, it is very difficult to attain equilibrium in this part of the ternary system. Coupled with the fact that the solubility limits of the σ-phase vary greatly with temperature, this introduces much uncertainty in drawing the phase boundaries. For an accurate delineation, very long periods of heat treatment would be required.

However, the results in the two-phase field $\gamma + \sigma$ and in the three-phase field $\alpha' + \gamma + \sigma$ are mutually consistent and the corresponding boundaries are not difficult to fix from the data at our disposal. The main difficulties arise in the neighbourhood of the point of contact of the $\alpha' + \gamma + \sigma$ triangle with the σ-phase. Here there are no doubt a number of transformations in the solid state, each of which remains to be thoroughly explored.

It is important to solve the structure of FeCr, and trace its relation to the body-centred cubic structure, since its formation may throw some further light on the transformations occurring in alloys nearer to the iron-rich corner of the diagram. The lines of the σ pattern are not always identical. Such variations are usually an indication that an alloy possesses two modifications. Possibly only one of these forms is an equilibrium phase, the other being an intermediate metastable product formed during the breakdown of the solid solution. It is possible that this process may be different according to whether the original solid solution was face-centred or body-centred cubic.

It is remarkable to find that the σ-phase is in equilibrium with the α'-phase over such a wide range of compositions. This conclusion is inevitable if the σ-phase is restricted to the narrow limits shown here for the binary alloys. However, as the temperature is lowered, the homogeneity range of σ rapidly extends towards the chromium corner of the diagram; even with 75% of chromium the binary alloys show a tendency to transform to the σ structure. It is therefore possible that at some lower temperature very long times of heat treatment would convert almost the whole range of α' structure to the σ type. There is much room here for further investigation.

Chromium-Rich Alloys.—Little work has been done near the chromium corner of the diagram. The corner of the $(\alpha' + \gamma + \sigma)$ triangle apparently lies very near pure chromium, and further investigation would be needed to test the effects of very small additions of iron and nickel to pure chromium. The three-phase triangle covers a wide area of the diagram, and in general outline has been completely surveyed. Here again there are certainly considerable changes with temperature, since this triangle must

completely disappear as the temperature is raised to the decomposition point of the σ-phase.

Acknowledgments.

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APPENDIX.—*X-Ray Data on Slowly Cooled Powders.*

The powders were cooled at 20–10° C. per hr. from 900° C., except for alloys lump-annealed at lower temperatures, where the powder-annealing began at the temperature of the lump-anneal.

Atomic Composition. %.			Lump Annealing. Temperature. °C.	Time. Days.	Phases Found.
Fe.	Ni.	Cr.			
15	65	20	1100	3	
15	50	35	1300	1½	
30	40	30	1300	3	
40	40	20	1100	3	
40	35	25	1100	3	
45	45	10	1100	3	γ only
62·5	17·5	20	1300	2	
62·5	12·5	25	1300	2	
65	30	5	1100	3	
67·5	17·5	15	1300	2	
70	25	5	1300	2	
72·5	22·5	5	1300	2	
72·5	2·5	25	1300	1½	α + trace γ (equilibrium not established)
			500	14	α
85	5	10	1100	3	No equilibrium
			570	9	α
65	10	25	1300	3	γ
			1000	3	$\alpha + \gamma$
			500	14	$\alpha + \gamma$
70	12·5	17·5	1100	3	$\alpha + \gamma$ (not in equilibrium)
70	5	25	1300	2	$\alpha + \gamma$
75	20	5	1300	3	Martensitic
			570	10	$\gamma + \alpha$
82·5	15	2·5	1300	3	Martensitic ?
			570	10	$\gamma + \alpha$
85	10	5	1100	3	Martensitic ?
			570	9	$\gamma + \alpha$
55	2·5	42·5	1300	2½	$\alpha + \sigma$
			500	14	$\alpha + \sigma$
60	5	35	1200	3	$\alpha + \gamma + \sigma$
65	5	30	1200	2	$\alpha + \gamma + \sigma$
40	20	40	1200	2	$\gamma + \sigma$
45	10	45	1300	2	$\gamma + \sigma$
45	15	40	1300	1½	$\gamma + \sigma$
50	5	45	1200	2	$\gamma + \sigma$ (α doubtful)
50	17·5	32·5	1300	2	$\gamma + \sigma$
50	22·5	27·5	1100	3	γ + trace σ
55	10	35	1250	2	$\gamma + \sigma$
55	30	15	1300	3	$\gamma + \sigma$
60	15	25	1200	3	$\gamma + \sigma$
40	2·5	57·5	1200	3	σ
40	5	55	1250	2	σ
45	5	50	1200	2	σ
5	2·5	92·5	1000	3	$\alpha' + \sigma$
25	5	70	1200	3	$\sigma + \alpha'$
20	15	65	1200	3	$\gamma + \sigma + \alpha'$
30	10	60	1200	3	$\sigma + \gamma + \alpha'$
35	25	40	1200	2	$\gamma + \alpha'$ + trace σ
35	20	45	1200	2	$\gamma + \alpha' + \sigma$

Atomic Composition. %.			Lump Annealing. Temperature.	Time.	
Fe.	Ni.	Cr.	° C.	Days.	Phases Found.
35	15	50	1250	2	$\gamma + \sigma + $ trace α'
35	7·5	57·5	1200	2	$\sigma + \gamma + $ trace α'
2·5	5	92·5	1300	3	$\alpha' + $ some γ
15	45	40	1250	2	$\gamma + \alpha'$
37·5	32·5	30	1200	2	$\gamma + $ trace α'
35	30	35	1300	2	$\gamma + \alpha'$

CORRESPONDENCE.

Mr. J. H. G. MONYPENNY (Messrs. Brown Bayley's Steel Works, Ltd., Sheffield) wrote that one of the most prominent features of the iron-chromium-nickel alloys was the slow rate of many of their phase changes, particularly of those which took place below a low red heat.   This fact having been demonstrated by previous investigators who had heated their alloys for periods of up to 1000 hr. at temperatures in the range 600–800° C. in an effort to attain equilibrium, it was a matter of considerable surprise to find the authors of the present paper stating that their object was " to obtain a survey of the whole system at a lower temperature than previously " and yet basing their survey on the examination of samples cooled at such a rate that, in many of them, anything approaching equilibrium was unlikely to be obtained.   The effects of this could be plainly seen in many of the differences (to which the authors referred) between Fig. 1 in their paper and the diagram drawn by Schafmeister and Ergang on the results of their very careful and extensive investigation, and was particularly evident in the positions of the boundaries of the σ-containing fields towards the iron corner of the diagram.

The question as to whether a homogeneous σ phase might exist over a small range of composition in pure iron-chromium alloys (as previous investigators had found) or was confined solely to the 50/50 alloy, as the present authors suggested, was of considerable theoretical importance and would doubtless be settled in time.   It might be noted, however, that Jette and Foote [1]—with whose work the authors did not seem to be acquainted—had shown that the $\alpha \underset{\rightarrow}{\overset{\rightarrow}{\rightleftarrows}} \sigma$ transformation was reversible in pure Fe–Cr alloys at a temperature between 775° and 800° C., and that it took place very slowly in both directions, though the rate of change was greatly accelerated by prior cold-work.   Thus, they showed that stress-free powder from an alloy containing 50·6 atomic-% of iron contained only a trace of the σ phase after being held for 250 hr. at 600° C., whereas a similar sample, after lightly rubbing in an agate mortar, was wholly converted to the σ phase by holding for 24 hr. at the same temperature.   As the authors' method of annealing would involve their alloys (which had been stress-relieved after powdering) being in the range 800–600° C. for 10–20 hr. only, it was unlikely that equilibrium was always obtained, and while this might perhaps account for a homogeneous σ structure being obtained only in one pure Fe–Cr alloy, it was almost certainly the cause of their failure to find this phase in Fe–Cr alloys containing less than 42·5% of chromium.   In this connection it was perhaps sufficient to note that Burgess and Forgeng,[2] for example, found that

[1] *Metals and Alloys*, 1936, vol. 7, p. 207.
[2] *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1938, *Iron and Steel Division*, vol. 131, p. 277.

an iron-chromium alloy with 39·7% of chromium contained approximately 50% of the σ phase after annealing at 700° C.

Similar remarks applied to the boundaries, towards the iron corner, of the α + σ, α + γ + σ and γ + σ fields in alloys containing up to about 20% of nickel. Among the authors' alloys were four containing 25% of chromium together with 2·5%, 5%, 10% and 12·5% of nickel, respectively, and in none of these did they find the σ phase. All these alloys lay within the limits of one or other of the three fields, mentioned above, in Schafmeister and Ergang's diagram, and the following results, taken from the latter's paper, regarding the change in the properties of an alloy containing 25% of chromium and 6% of nickel on annealing at 650° indicated the probable reason for the authors' failure to obtain evidence of the σ phase in their alloys :

Treatment.				Inductance, Gauss.	Brinell No.
W.Q. 1200° C.	.	.	.	8910	186
,, ,,	200 hr. 650° C.		.	3530	218
,, ,,	1000 hr. 650° C.		.	2910	261

As these results showed that equilibrium was not attained after heating for even 200 hr. at 650° C., it seemed obvious that the authors' method of annealing was quite inadequate to allow the sluggish α → σ change to occur to an extent measurable by their X-ray technique.

An interesting feature of the authors' diagram—though of less practical significance, owing to the poor physical properties of the alloys concerned—was the extent of the α' + γ + σ and α' + σ fields, which reached almost to the chromium corner of the diagram and thus differed widely from those in the German diagram. The authors' results, if correct, would make it somewhat difficult to visualise the probable constitution of the σ phase. An examination of their data suggested, however, that the boundaries for these fields had been positioned mainly, if not entirely, on the results from two alloys containing respectively chromium 92·5% and nickel 2·5% and chromium 65% and nickel 15%, both of which were stated to contain the σ phase. Schafmeister and Ergang reported on the difficulties in determining structural changes in alloys within this range of composition, but it should be noted that they were unable to detect σ formation in an alloy containing 70% of chromium and 10% of nickel after prolonged annealing at both 650° and 800° C. According to the authors' diagram, an alloy of this composition should contain a considerable amount of this phase. In this connection one might ask whether the stated compositions of the authors' alloys were checked by analysis ; the values in the Appendix gave the impression that they merely represented the " type " compositions at which the authors aimed. If this was the case, their results would be more convincing to a metallurgist if these compositions were actually checked by analysis. Previous in-

vestigators had also found that these very high-chromium alloys absorbed nitrogen with avidity at high temperatures; had the authors determined whether appreciable contamination of their alloys by this element or by other impurities occurred during melting ?

The iron-chromium-nickel alloys were of very considerable practical value as corrosion-resisting and heat-resisting materials, and hence the ternary diagram was not only of theoretical interest but also of great practical importance. The fact—already well established—that the σ phase had properties which rendered it an undesirable constituent of alloys used for many purposes, particularly those involving the alloy being heated for long periods at a red heat during use, made it important that the boundaries of the fields in which it could occur—especially those towards the iron corner of the diagram, where many alloys of industrial importance were located—should be known with fair accuracy. For the reasons given above the authors' diagram could not be regarded as being in any way an advance on existing knowledge.

The authors stated that their work was intended to form a basis for later investigations; might one hope that in these later investigations the authors would realise the necessity of taking more effective steps to obtain equilibrium in the alloys which they examined. If so, the publication of the present paper would have served some useful purpose.

AUTHORS' REPLY.

The AUTHORS thanked Mr. Monypenny for his valuable criticism. It was not denied that transformations would occur with still slower rates of cooling; in any case it was impossible to devise any experiments which would produce perfect equilibrium at lower temperatures. At the best, therefore, in a rapid investigation such as the present one, one must choose between equilibrium at a high temperature and a survey at a lower temperature. Equilibrium might perhaps be obtained at 800° C. after a reasonable time of heat treatment, but in many cases it was impossible to preserve the alloys in this condition by quenching. The courses available might be summarised as follows :

(1) Quenching of microsections.
(2) Quenching of powders for X-ray analysis.
(3) X-ray investigations in a high-temperature camera.
(4) X-ray photographs after cooling at the rate specified in the present paper, or at a slower rate.

Schafmeister and Ergang, by combining X-ray and microscopic work, made use of methods (1) and (2); the authors had used method (4). X-ray work unaided by the microscope must use the slow-cooling method to avoid possible confusion from transforma-

tions during quenching.   The alternative use of a high-temperature camera was not practicable in a rapid survey.   The purpose of such a survey was purely exploratory, and it was claimed that this provided the easiest way of making a preliminary attack on an alloy system, because it most readily indicated which compositions would be fruitful in yielding interesting results.

Further investigations would inevitably involve the combined use of X-rays and the microscope.   The alternative use of the high-temperature camera was not recommended, being too slow compared with the microscope.

With regard to the cooling rates, 10° C. per hr., which had been arbitrarily chosen, was merely selected as being a convenient rate for giving X-ray photographs which were capable of interpretation.

On slowly cooling small samples of powder *in vacuo* from 900° C. to room temperature it seemed probable that conditions might correspond to equilibrium at a lower temperature than might be expected from the results of experiments on block samples annealed at a fairly high temperature and examined by a microscope.   A comparison of the extent of the $\alpha + \gamma$ field in the authors' diagram with that given by Schafmeister and Ergang for 650° C. supported this contention.   Alloys which, according to the latter, were well within the γ-area, were two-phase after the authors' treatment; the present $\alpha + \gamma$ area extended throughout to higher nickel contents.   In fact, many of the differences from Schafmeister and Ergang's diagrams at 800° and 650° C. (as reproduced by Mr. Monypenny [1]), though not all, could be explained by regarding the authors' phase boundaries as applying to a temperature lower than 650° C., since in this case they would be in consistent continuation of the displacements of boundaries between 800° and 650° C.   This was mentioned to show that the authors' heat treatment was at any rate as adequate in yielding a low-temperature equilibrium as that of most previous investigators.

Regarding the portions of the diagram involving the σ-phase, the authors agreed that a more prolonged heat treatment at low temperatures would be desirable.   Separate studies would be necessary to decide the treatment most favourable in each phase region. As said before, this was not within the scope of this work.

The formation or inhibition of the σ-phase in pure Fe–Cr alloys seemed to depend very critically upon the treatment, particularly the rate of cooling.   The authors did not suggest that in true equilibrium the σ-compound was restricted to the exact composition 50% chromium.   On the contrary, they said that the range of the σ-phase contracted with rising temperature, implying the existence of a range.   In this connection, it might be mentioned that on quenching powders of the alloy FeCr from a series of temperatures, a systematic change of the relative amounts of α and σ phase was

[1] *Metallurgia*, 1940, vol. 23, p. 87.

observed, showing a maximum of σ between 600° and 800° C.; while 45 hr. at 575° C. yielded predominantly σ, the same time at 420° C. yielded pure β.   This was evidently due to low-temperature sluggishness in the formation of the σ-phase, as mentioned by Mr. Monypenny, and it was true that, owing to this feature, the ternary α + σ and α + σ + γ regions might have been placed too far away from the iron corner.   In this important region, however, the very erratic γ–α transformation (pseudo-martensite) was superimposed upon the α–σ one, so that the true boundaries were as yet far from being established.

Regarding the chromium-rich corner of the diagram, it was unexpected to find the σ-phase in alloys as high in chromium as that containing 92·5% of chromium and 2·5% of nickel.   The evidence for this wide range of existence of σ was derived not only from the two alloys mentioned by Mr. Monypenny but also from a series of alloys in the γ + α' and γ + σ + α' fields, e.g., the sequence containing 35% of iron, which, though more distant from the chromium corner, served, from relative intensities, to locate the boundaries of the γ + σ + α' triangle.

In contrast to Schafmeister and Ergang's results in a similar region, the authors' alloy containing 70% of chromium and 5% of nickel showed a considerable amount of σ.   They wished, however, again to emphasise the need for further work in this part of the diagram.   They were fully aware of the danger of contamination of the chromium-rich alloys by nitrogen or other elements.   However, they thought that by melting the alloys under hydrogen in the induction furnace, after previous evacuation (the procedure adopted), any danger of nitrogen pick-up should have been mini-mised.   The nitrogen content of the chromium used was, as stated, 0·20%, which, they agreed, might be higher than was desirable.

The compositions of the alloys corresponded to those of the charge for the melt, which had been carefully weighed out; a check by chemical analysis was not made; the authors appreciated that this would be valuable, but the accuracy of the predetermined com-positions was considered sufficient for a preliminary survey intended to establish the general outlines of the diagram.

Further Discussion on

THE THERMAL RELATIONS BETWEEN INGOT AND MOULD.

By T. F. RUSSELL (SHEFFIELD).

Paper No. 4/1940 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Stresses in Moulds Panel of the Ingot Moulds Sub-Committee).

This paper was presented at the Annual General Meeting of the Institute held on May 1st, 1941, and will be found, together with the correspondence to which it gave rise, in the *Journal of the Iron and Steel Institute*, 1941, No. I., p. 163 P. Later it was discussed at a Joint Meeting of the Institute with the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association held at the Royal Victoria Station Hotel, Sheffield, on Saturday, October 4th, 1941, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of the Institute); a synopsis, the discussion and the author's reply are recorded below.

SYNOPSIS.

Saitô's formulæ for the distribution of heat between ingot and mould are examined quantitatively. The practical variations from the ideal case are discussed, and it is thought that the possibility of deriving more exact formulæ from Saitô's is very remote.

Examples are worked out for circular and square ingots of the same cross-sectional area cast into moulds of four different thicknesses. Curves are drawn showing the temperature at different points in the ingot and moulds, the temperature distribution across a diameter and the total quantities of heat in the ingot and mould at different times. Curves are also drawn to show the effect of "mould ratio" on the temperature cycle occurring in the ingot near to the mould wall and on the time taken for the temperature at the centre of an ingot to fall certain amounts representing solidification. The latter show that solidification is accelerated by increasing the mould thickness until the mould ratio is about 0·8–1·0, but that further increase in mould thickness has an inappreciable effect.

Four sets of experimental results on the measurement of mould temperature are examined, and they show that the greatest difference between theory and practice is found at positions in the mould near to the inner face. This is attributed to the effect of the air-gap forming between the ingot and the mould.

DISCUSSION.

Dr. W. H. HATFIELD, F.R.S. (Brown-Firth Research Laboratories, Sheffield) said that in all their investigatory work they came to the limit of experiment—they all recognised that, particularly with the subject of ingots—and then they had recourse to the possibilities of mathematical interpretation, and anyone who once

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started that had taken on a heavy task. To begin with, anyone who tackled the mathematical side of the problem must assume certain factors, and no doubt Mr. Russell and their various other friends who tackled problems from a mathematical point of view assumed certain factors after very careful consideration. But, even so, only a great amount of personal work could do anything with those factors, and he did not think that all of them, when they just cursorily looked over Mr. Russell's paper, really weighed sufficiently the great mass of work that the author had actually personally put into it.

Mr. T. LAND (Messrs. William Jessop & Sons, Ltd., Sheffield) said that two points of interest arose from Mr. Russell's work which should be commented on. The first was that the author had shown that one could obtain at any rate a fair degree of correspondence between the actual temperature relations in a mould and the theoretical relationships which could be calculated by mathematical methods. That, he thought, was something; it was much better to have some relation than none. Secondly, Mr. Russell had made a definite contribution to the theory of ingot-mould design by his investigation of the effect of mould ratio, and, in particular, by showing that beyond the mould ratio of 1 there was no particular advantage in increasing the thickness of the mould.

The speaker had recently been making a few investigations of the stresses in ingot moulds, and he had had occasion to use the same formula that Mr. Russell had been using. The results would shortly be communicated, through Mr. Oliver, to the Committee concerned.[1] In the course of that work one or two points arose which might be of interest.

It was very difficult to discuss these mathematical matters in a way which would be of general interest to everybody concerned. The particular problem on which he would like to comment was that of very thin ingot moulds, and he thought that Mr. Russell would agree that they found it very difficult, in using the Dini expansion which Saitô used, to get arithmetical results, because the expansion converged very slowly. He therefore put forward a suggestion which might be of interest to Mr. Russell. That gentleman had mentioned that for a short time the interface temperature remained at a steady value. If one accepted that as a starting point instead of more complicated conditions, and if one also considered the thin mould to be an infinite plate without any curvature, he had found that it was possible to get an expression for the temperature at any point which was in very reasonable agreement with the more complicated formulæ, and, furthermore, only two instead of about twelve terms in the expansion were required. It also had the advantage that it was possible to make allowance for the different thermal constants of the cast iron and

[1] *See* this *Journal*, p. 157 P.

the liquid steel, because the interface temperature would be determined by those thermal constants. Also, it was possible to make allowance for the latent heat of solidification of the steel. The formula was, however, only valid for small values of the time.

Mr. J. WOOLMAN (Brown-Firth Research Laboratories, Sheffield) said that they were all agreed that the work was of very great use and value to the people who were concerned in the study of heat transference in large masses, particularly in ingot moulds, but he failed to see how this work could apply to the actual problem that they had in mind, which was the calculation of the stresses, particularly as they had already determined in a practical way the temperature distribution in the rectangular mould for which the author had tried to produce his calculations. If Mr. Russell could superimpose on the formula for temperature distribution through the mass of the steel, in both the mould and the ingot, equations representing the stresses and solve those equations, then it would be a great step forward, but the speaker was afraid that for a rectangular mould that was a difficult problem, though it was comparatively easy for a circular mould. He thought, nevertheless, that Mr. Russell had brought out one or two very interesting points. The first was that, for the size of ingot mould with which he had been concerned, there was no advantage in having an ingot-mould ratio in excess of 1. The value of 1 was in accordance with modern practice, and it was interesting to see that it had been confirmed by direct mathematical calculations. But it would be interesting to know whether that ratio of 1 applied to other sizes of mould apart from the particular size with which Mr. Russell had been concerned. He was glad that Mr. Russell had emphasised the point about the break in the curve at the ingot-mould base, because in the past people had made the point that that break corresponded to the time of separation of the ingot from the mould. They now knew that that was not necessarily the case. But the question of the separation of the ingot from the mould did introduce a serious error in the calculation for temperature distribution, and the differences between theory and practice, shown by Mr. Russell's curves, were partly due to that fact. There were other causes of the difference. The principles on which the mathematical formulæ were calculated introduced certain assumptions which they knew were not true, and they all went to make the mathematical calculations depart from what actually occurred; nevertheless, he thought they would all agree that Mr. Russell had done a great service in carrying out these calculations.

Dr. W. R. MADDOCKS (University of Sheffield) asked Mr. Russell to enlarge on the metallurgical significance of the use of thin-walled moulds. He was under the impression that in thin-walled moulds the expansion longitudinally was great, and that if the

major part of the expansion took place before the formation of the air gap the surface of the ingot would be torn. He would like to have Mr. Russell's opinion on such possibilities.

Mr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) said that Mr. Russell had indicated that when an oval or circular mould was used one side of which was much thicker than the other, the cooling of the steel was quicker at first on the thinner side. Now, since it was undoubtedly desirable that ingots should set from the bottom upwards, he would suggest that a mould with heavily tapered walls be tried, the greatest thickness being, of course, at the top.

Mr. RUSSELL referred to the Granat and Bezdenezhnykh [1] experimental mould which was parallel-sided but eccentric. Their test results showed that in this mould the part of the ingot near to the thin walls had cooled faster than that part near to the thick wall, and he (Mr. Russell) had pointed out in his paper that that was probably because heat had passed round the mould from the thin to the thick side. The type of mould suggested by Mr. Whiteley would not, in his opinion, be effective in promoting the setting of the ingot from the bottom upwards. The greater mould thickness at the top would promote solidification there, and any heat passing up from the bottom of the mould would be quite inadequate to compensate for the additional chilling effect of the thicker wall.

Dr. R. JACKSON (Messrs. Hadfields, Ltd., Sheffield) said that at the end of the paper Mr. Russell referred to the difficulty of working out one particular calculation, because the Bessel functions were tabulated only to the first eight terms. Could he give them any idea how accurate the original calculations were by comparing the present results with those obtained by taking only the first seven terms into account. If the difference between the two sets of results was appreciable, then the validity of the present basis of calculation would be in doubt.

One of the assumptions made was that there was no latent heat of solidification. There was, of course, definitely this latent heat. Later in the paper, considering the mould ratio, a maximum casting temperature of $1650°$ C. was taken, and this was said to include the latent heat. Values quoted in the literature for the latent heat were very variable, but possibly the best accepted ones would be about 60 cal. per g., which would take the effective casting temperature up to somewhere about $2000°$ C., not $1650°$ C. as given, in which case with a solidus of, say, $1450°$ C. the value of U at the solidus would come down to 0.6 rather than 0.8, so that the optimum

[1] I. Ya. Granat and A. A. Bezdenezhnykh, *Metallurg*, 1938, No. 10, p. 19 ; *Foundry Trade Journal*, 1939, vol. 61, Nov. 16, p. 335.

value of the ingot-mould ratio as obtained from Fig. 2 would not, as stated in the paper, be unity, but considerably greater.

AUTHOR'S REPLY.

The AUTHOR thanked all those who had taken part in the discussion and particularly those who had shown appreciation of the amount of work required to take out the curves given in the paper.

He would like Dr. Hatfield, as Chairman of the Committee on the Heterogeneity of Steel Ingots, to know that a large amount of spade work, including the tabulation of about 1300 *roots*, was available to simplify any further calculations that the Stresses in Moulds Panel might recommend to be done. For example, Mr. Woolman, who was a member of that Panel, had raised the question of whether a mould ratio of 1 applied to other sizes of ingots. He (Mr. Russell) would be pleased to have other calculations made if the Panel thought them desirable.

Mr. Woolman stated that " he failed to see how this work could apply to the actual problem that they had in mind, which was the calculation of the stresses, &c." These stresses were primarily due to the temperature gradients, and surely it was obvious that the first thing to do was to investigate as far as possible these temperature gradients. The difficulty in proceeding to the next step, *viz.*, the calculation of the stresses from the temperature gradients lay in the fact that all formulæ used for this purpose, at present known to the author, presupposed that the material was isotropic and had a constant modulus of elasticity over the range of temperature attained by the material. This was far from being true for cast iron.

He would look forward with interest to seeing Mr. Land's suggested new treatment to cut down the amount of arithmetic work.

The best reply to the first paragraph of Dr. Jackson's contribution was to invite him to inspect the actual calculations, which were at the disposal of anyone interested. He would find that all the curves drawn were accurate to $U = 0{\cdot}001$ for relatively small times and that most of the figures were recorded to $U = 0{\cdot}000001$. For all practical purposes there was no difference between the first seven and first eight terms, but for very small times eight terms were not enough.

Dr. Jackson would find on p. 173 P of the paper [1] that 356° C. had been added to the solidus temperature of 1450° to allow for the combined effect of latent heat and superheat, making an initial temperature of 1806° C. In this connection Dr. Jackson should be interested in Mr. A. L. Feild's contribution to the discussion, also to be found in the same *Journal*. The figure 1650° C. was stated in the

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[1] *Journal of the Iron and Steel Institute,* 1941, No. I.

paper to have been found to be the best value to use for the initial temperature, so that the theoretical curves and practical curves would fit. This value was then used in other trials.

Dr. Maddocks had raised an interesting question about the effect of thin-walled moulds on the ingot itself. The paper showed that for the same size of ingot, the thinner the mould the hotter it became and therefore the greater the amount of expansion. What effect this had on the ingot of steel he could not say from his own personal observations. Experiments at the English Steel Corporation had, however, shown that with an ingot mould having relatively thin walls, it was possible to fill the gap between the mould and ingot up to 2–3 in. from the level of the steel during the casting of the ingot. The gap must therefore have formed very quickly, and probably before the full effect of the longitudinal expansion of the mould could have any effect on the pulling of the ingot. Experiments and general observations indicated that before longitudinal mould expansion could be operative the outer shell of the ingot was sufficiently rigid to safeguard against cracking.

Further Discussion on

THE FORMATION AND PROPERTIES OF MARTENSITE ON THE SURFACE OF ROPE WIRE.

By E. M. TRENT, M.Met., Ph.D. (The Royal School of Mines, London).

This paper was presented at the Annual General Meeting of the Institute held on May 1st, 1941, and will be found, together with the correspondence to which it gave rise, in the *Journal of the Iron and Steel Institute*, 1941, No. I., p. 401P. Later it was discussed at a Joint Meeting of the Institute with the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association held at the Royal Victoria Station Hotel, Sheffield, on Saturday, October 4th, 1941, under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of the Institute); a summary, the discussion and the author's reply are recorded below.

Summary.

The occurrence of thin layers of martensite on the worn surfaces of wires in wire ropes used for mining is described. These layers are very easily cracked, and the cracks lead to a rapid failure of the wires through fatigue. This produces a very dangerous form of deterioration, particularly in mining haulage ropes.

During friction the rope may frequently seize or weld locally on to the object against which it is rubbing, and a thin layer of the object may be torn away and remain adherent to the wire surface.

The metallurgical structures of these thin layers are described. Martensitic surfaces similar to those found in service were reproduced on wires in the laboratory by a number of methods, such as striking the wire a glancing blow with a hardened steel tool or rubbing the wire with a steel tool under heavy pressure. These layers are examined metallurgically and their effect on the mechanical properties of the wire is examined briefly. The cause of a certain type of corrosion pitting known as " chain pitting," which occurs in service on the worn surfaces of wires in haulage ropes, is traced to a localisation of corrosion at cracks in a martensitic surface.

DISCUSSION.

Mr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) said that it might interest Dr. Trent to know that he had occasionally seen a small amount of martensite in the head of an ordinary steel rail, brought about by the friction of the wheels on the rail.

There were two or three points in the paper that he was not sure about. For instance, Dr. Trent said, on p. 403 P, " Ferrite streaks at the grain boundaries of the steel are frequently not dissolved into the austenite on heating, and are visible in the martensite.

This is probably due to the fact that, although they are thin, these streaks of ferrite are many times thicker than the cementite laminæ of the sorbite, and hence would take longer to dissolve." That was no doubt true, but there was another explanation. It might be that the temperature reached had not been high enough for the ferrite to disappear.

In the same paragraph, Dr. Trent said, " A coarser structure would require either a longer time or a higher temperature for the complete transformation to austenite." That was an assertion ; had the author made an experiment to see whether a longer time was needed ?

Dr. TRENT replied no, they had had that in mind.

Mr. WHITELEY said he was inclined to think that Dr. Trent would find that there was very little difference between the speeds at which relatively coarse and very fine structures disappeared.

Another assertion was that nitrogen was not present in the hard layers, but he did not find any valid evidence in support of that statement. Nitrogen could form a constituent braunite, which resembled pearlite, but it separated at about 600° C., instead of 680° C., so that if Dr. Trent tempered the thin layers of supposed martensite in an inert gas at, say, 650° C., he might find that a certain amount of braunite had formed. Anyway, he (Mr. Whiteley) thought that sufficient attention had not been given to the absorption of nitrogen in the layers.

Dr. Trent had described the dark substance in Fig. 14 as martensitic needles. An examination of this structure with a hand lens, however, failed to show any of the needles so characteristic of martensite. He (Mr. Whiteley) would suggest that it was either due to nitrogen or that troostite had been precipitated at the grain boundaries, for the structure seemed to be reticulated. If these hard layers were really martensite he would suggest that the use of a low-manganese steel, containing, say, $0 \cdot 1 \%$ or less of that element, might be considered, since the formation of martensite was greatly facilitated by the presence of manganese in steel.

Dr. W. H. HATFIELD, F.R.S. (Brown-Firth Research Laboratories, Sheffield), asked if Dr. Trent had actually determined that this substance was martensite. He did not see any record of hardness tests.

Dr. TRENT replied that there were no hardness tests.

Dr. HATFIELD commented that Mr. Whiteley was quite right. The author was not entitled to go too far in explaining the properties of the layer unless he had established its nature. He deserved to be criticised for not having made hardness tests.

Secondly, a work-hardening effect under those conditions would

produce great hardness. Without having gone over his ground experimentally, he could have that local surface work-hardening effect without the martensite effect. So, on those two grounds, he thought that it remained for the author to really prove that what he was talking about was martensite.

Mr. E. T. GILL (I.C.I. (Fertilisers and Synthetic Products), Ltd.) said that he could confirm that the hardness of the layer, with which he had been very familiar in the past, was of the order what one would expect from martensite—in the region of 600 Vickers hardness. It was determined with the diamond tool, using a very low load. He could not give accurate figures now for the depth of the layer, but it should be appreciated—as he thought the paper showed—that as an individual wire was being continually abraded during the course of its service life, the hardened layer produced gradually increased in depth, so that one could select wires having a sufficiently deep layer—of the order of 0·005–0·010 in.— upon which to make a reasonably accurate hardness determination.

Dr. HATFIELD pointed out that a similar reading could be obtained from a work-hardened surface.

Mr. GILL replied that the work-hardened surface would certainly not give the effects demonstrated by the micrographs in Dr. Trent's paper. When a longitudinal microsection, cut at right angles to the worn surface so as to show the depth of the " foreign " zone, was etched only sufficiently to bring up the usual cold-worked structure of the wire, it was found that the region immediately beneath the worn surface remained unattacked by the etching reagent to the depth of a few thousandths of an inch. Somewhat deeper etching obviously intensified the attack on the normal drawn structure, but, in addition, tended to make the " foreign " zone slightly brown.

Mr. WHITELEY interposed that martensite did not etch brown.

Mr. GILL admitted this, but suggested that, except for the extreme edge, the zone under discussion was troosto-martensitic, as a result of the tempering effect of the heat created by abrasion subsequent to the formation of the martensitic layer.

Dr. TRENT pointed out that Fig. 3 showed that.

Mr. GILL, continuing, said that, while he was convinced that the layer was martensitic, he could not confirm that he had ever been able to see the typical needle-like structure that would be more convincing to Mr. Whiteley than the effect he had been criticising. He felt sure that one or two people associated with the steel wire trade who were present at this meeting would confirm his belief

that the layer under discussion was martensitic or a very near derivative.

Dr. HATFIELD said that Dr. Trent had put forward a lot of data on martensite, without, on his own admission, having quantitatively determined the hardness of the constituent.

Mr. GILL agreed with the criticism, but added that he was attempting to give evidence in support of Dr. Trent's statement that it was martensite.

Dr. HATFIELD said that they welcomed Mr. Gill's help to the author, but the thing that caused him to take just a critical interest from this angle was that they were dealing with an aggregate of wires, each of which was of only small sectional area, and they were presuming a quenching effect from that wire of the order that one would get in a much heavier mass of steel. The martensitic layers were well-known on rails. Every railway tyre between Sheffield and London, or at least 90% of them, had as a distinctive feature stress raisers in the form of a network of cracks, in a material having an impact value of 3 ft.lb., but the sectional area was very considerable. Now here they had not that attendant condition, so that one was justified in questioning whether the subject of the paper really existed.

Mr. GILL said that Dr. Hatfield had challenged Dr. Trent with the question " Have you made any test to confirm that that is martensite ? " and he cited particularly, he believed, a hardness test. He was confirming that, so far as he was concerned, he had in the past done that and got Vickers hardness values of the order of 600. That was not entirely conclusive, he agreed, but he thought it went a long way.

Dr. HATFIELD pointed out that if it were martensite in a carbon steel the hardness would be more than 600 Vickers diamond ; it would be more of the order of 750.

Mr. GILL replied that he had already indicated that there was a tempering effect, which would reduce the hardness from the value quoted by Dr. Hatfield to that which he had just given.

Dr. TRENT said that Dr. Hatfield pointed out that he (Dr. Trent) had made no confirmation of the fact that this was martensite, and had suggested the use of the hardness test. Then when Mr. Gill put forward his hardness tests, Dr. Hatfield said that they were no proof. That was precisely why he did not do the hardness test, because the hardness tests themselves were not conclusive that the material was martensite.

Dr. HATFIELD said he could have used the scratch test.

Dr. TRENT replied that from what he had seen of the scratch test he was not impressed with its reliability as a quantitative test.

Dr. HATFIELD pointed out that it was made the measure of reliability for the identification of the constituents in steel. Dr. Trent might have applied the same principle.

Dr. TRENT said that he had not reproduced the photographs, but he had tempered the material at various temperatures, and had no doubt that it became sorbitic at the higher temperatures near the lower critical point, and also that this tempering did occur in action by the overlaying of one martensite layer by another, which was illustrated in Figs. 3 and 5.

Mr. WHITELEY remarked that it could be sorbitic at 400° C.

Dr. TRENT agreed, but added that it was not so easy to tell that it was sorbitic at those temperatures—one could not distinguish the actual particles. It became black ; it etched jet black at temperatures of the order of which Mr. Whiteley was speaking.

Mr. H. ETCHELLS (Messrs. L. Cameron & Son, Sheffield) asked whether it could be assumed that the material reacted to hardness tests of this type ? Presumably a transformation of this kind might produce a material which was very finely dispersed and might contain two or three constituents, and these physical tests were rather crude in dealing with such minute sections. It seemed a problem more for investigation on the lines of X-rays or something of that kind.

Dr. M. L. BECKER (Messrs. David Brown & Sons (Hudd.), Ltd., Huddersfield) said that he supported Dr. Trent in his assertion that the constituent on the surface of his wires was martensite. He had examined a number of sorbitic or martensitic steels in which the surface had unquestionably been rehardened as a result of frictional heating. The appearance of tempered bands underneath the surface layer was in itself strong support that the surface layer consisted of martensite. The rate of etching of the surface martensitic layer was generally less rapid than that of the martensite of the main body of a hardened tool steel, and this often permitted differentiation under the microscope, although the martensitic structures might be indistinguishable. The character of these thin surface layers was not readily shown in micrographs, and he thought that the illustrations in the paper were a credit to the author.

A most interesting example of a martensitic layer was shown in Fig. 11. He had never seen a band of martensite developed by

shear action through the body of material except in steels which had been deformed as a result of explosion.   He had always thought that martensitic bands developed on shear planes were associated with very much more rapid rates of deformation than could possibly have occurred with a hammer blow, and he supposed that Dr. Trent had no doubt that the band illustrated in Fig. 11 was not a freak.   He knew it was difficult to show the structure of such a martensitic band in sorbitic material, because with deeper etching the latter became completely black and therefore appeared structureless.

He had often found martensitic layers developed where there had been an electrical discharge from the surface.   He remembered the case of a large rotor that had failed as a result of a fatigue crack starting from a small burn on the surface of the steel.   In such cases, as after welding, the evidence of local heating was generally more marked than on frictionally heated surfaces, but the results were the same, in that a hard brittle layer, very susceptible to cracking, was produced on the surface.

Martensitic surface layers were often produced while grinding hardened tool steels, &c.   Experience showed that, with a relatively coarse wheel, a quantity of material could be removed without the structure of the final surface of the steel being affected.   With fine wheels, although perhaps only one or two thousandths of an inch of the material were being removed, the final surface consisted largely of regenerated martensite.   He thought that the intense but extremely local heating was not due to the cutting action of the abrasive so much as to the rubbing or burnishing action of the metal picked up by these fine wheels, which tended to become slightly glazed almost immediately.   For this reason he would expect that a martensitic surface layer on haulage cables would be much more likely to be formed through rubbing against steel than through rubbing against rock, although the quantity of material removed by the rock would presumably be greater.   It would be interesting to know whether Dr. Trent had ever found martensite produced on the surface of cables through rubbing against materials other than steel or iron.

Professor J. H. ANDREW (University of Sheffield) said that Dr. Lee and he had been working on similar lines for many years, and he thought he could confirm everything that Dr. Trent had said. Dr. Trent had let him have one of these pieces of wire, which, after being cold-drawn, was given a blow with a hammer ; this showed the white band of austenite and martensite structure.   They examined it and found exactly the same white line that Dr. Trent had shown.   Then they made a Vickers hardness test, and obtained an impression dead in the centre ; that gave them a hardness of over 600, whereas that of the surrounding metal was under 400.   On tempering at 250° C., the hardness of the white band went up to

630, showing that not only martensite but also a certain amount of austenite was present.   It was his contention that in any drawing process they must obtain austenite during that process.   He thought all cold-drawing operations would produce martensite or austenite, as the case might be.

If they pulled an air-hardening nickel-chromium steel in a test machine—one which would give them about 50% reduction of area—and measured the hardness along the broken test-piece, they would find a slight increment from the head to near the point of fracture, where the hardness showed a drop of 100.   On secondary hardening, the value went up by 200.   He thought Dr. Trent had every reason for assuming that it was martensite in these steels ; he would go further, and say that some of the so-called martensite might be partly austenitic.

Dr. Trent implied that this austenite was simply due to the heating effect, but he (the speaker) wondered whether the mechanical distortion of the atoms might not be regarded as sufficient to change its form.   The effect of mechanical work on the lattice structure should be taken into account.

Mr. P. WOODHEAD (British Ropes, Ltd., Doncaster) said it was misleading to say that wire was used in a sorbitic condition. It was used in a drawn sorbitic condition.   Heat-treated and tempered wire was no good whatever for mining ropes.   It had been stated in the paper that when a wire rope went round a pulley and round a bend in the road, it probably got stretched beyond its limit of proportionality.   He would point out that the limiting fatigue stresses of wire were considerably below the limit of proportionality, and fatigue effects were produced even if it was not stretched beyond its limit of proportionality.

With regard to the flowed skin, he had been watching it for over twenty years, and he was not altogether in agreement that it was martensite.   He had etched it with all known reagents, and never gained the triangular formation of martensite in that flowed layer. Personally he thought it was an amorphous skin that was formed by the friction ; he did not think martensite had much to do with it.

Furthermore, he would like to know whether the analysis of the wires which had been examined had been taken with sufficient care to tell whether there was any residual chromium in the wire, left from a previous steel melting charge.   He had proved that a small percentage of chromium in an ordinary steel wire made that wire very susceptible to martensite formation.   As a matter of fact he had a sample where the martensitic layer was about 0·02 in. under the skin of the wire after two passes in drawing.   He had micrographs to show that it was martensite that was produced by a small percentage of chromium, although the total chromium content of that wire was only 0·08%.   There was no doubt about it being

martensite in that case ; there was no nickel, or very little—it was principally chromium.

He was partly of the opinion that the needle formation shown might be due to nitrogen. He was not sure about that, but it was typical of the nitrogen needle.

All wire-drawers did not use modern methods of production, and, that being so, how was it that under heavy reductions, up to 25% on one draught, the wire-drawer did not produce a martensite coat on his wire with an ordinary alloy die. He never did, though he often drew wire to such an extent that he drew off his drawing coat, and scraped it, but he never found such a martensite layer produced.

He considered that the paper had been pretty well done, but contended that it did not go quite far enough, and at the present stage it was likely to be misleading. For a start, the usual colliery engineer knew nothing about metallurgy—nor did many other people, such knowledge being unnecessary—and once such an engineer read in a paper that martensite was produced in a haulage rope he would be inclined to say immediately " That is the fault," without considering that there was the possibility of twelve tubs being put on instead of eight, some tubs coming off the line, haulage continuing and the rope breaking. The rope manufacturer had some good friends, who found the causes of these breaks, but sometimes it was impossible to get to the truth about such usage.

Dr. A. G. QUARRELL (University of Sheffield) said that he agreed with the last speaker that it was almost certain that on the surface which Dr. Trent described there was an amorphous layer, but it was not the layer which was shown in the micrographs. By electron-diffraction the flowed layer on various metals had been examined, and there seemed to be no doubt that, by burnishing such as Dr. Trent was talking about, the true surface layers were amorphous. Certain workers had measured the thickness of this flowed layer, particularly on gold, a metal which was very easily polished and on which it was easy to produce a relatively thick flowed layer. The estimates that he had in mind were made by two different methods by two different workers, and they agreed exactly as to the order of the thickness of that flowed layer, which was 50 Å. Below 50 Å. the crystalline structure of the gold was very well developed, and it was easy to produce a relatively thick flowed layer on gold, much easier than it was on carbon steel. Electron-diffraction evidence also showed that there was an amorphous layer on burnished steel specimens, but that was the true surface layer, not a relatively thick layer such as Dr. Trent was examining.

Dr. HATFIELD asked if that method of attack permitted Dr. Quarrell to state that the metal was not even meta-crystalline ? An " amorphous condition " was very definite. He challenged the

ability of the line of attack referred to to produce the evidence that Dr. Quarrell claimed to have produced.

Dr. QUARRELL replied that the only other way in which one could explain the electron-diffraction patterns from flowed layers of just one particular metal, such as gold, was by assuming a crystalline size of approximately one unit cell. That was, if one confined one's work to one metal such as gold, but if one took into consideration the other metals which had been examined, then one found that not even by reducing the crystal size to that extent could one get the two diffused halos in the positions where they were observed. Bearing in mind the diffusion of the halos, there was reasonably good agreement between the positions of those halos and the idea that the surface layer was, as it were, supercooled liquid.

Dr. HATFIELD wished it to be noted that he had registered an objection to that view. He did not believe it. Dr. Quarrell was begging the question.

Dr. QUARRELL disagreed.

Dr. HATFIELD, continuing, said that Dr. Quarrell was begging the question by extending a view based on a small amount of experimental evidence as a side issue in a discussion on another matter, and he was assailing a fundamental position. Now the fundamental point was this : Could these industrial metals exist in the amorphous condition or not. He (Dr. Hatfield) had no evidence, in the whole of his long contact with the subject, to support that view.

Dr. QUARRELL submitted that Dr. Hatfield had not had the experimental technique at his disposal for discovering a layer 50 Å. thick. As far as he knew, the only method at present available was electron-diffraction. And it was not the result of a small amount of work. Practically every worker in the electron-diffraction field had tilted at the amorphous layer, and he thought it had been proved, reasonably conclusively, that the result of burnishing or polishing metal was to produce an amorphous layer. Furthermore, he wished to submit that the evidence was relative to the case in hand.

Dr. HATFIELD said they would take note of it, but he did not accept it.

Mr. E. T. GILL said that it appeared to him that Mr. Woodhead had postulated—he was not quite sure whether the last speaker was confirming what Mr. Woodhead had said—that this layer was not of a martensitic type.

Dr. QUARRELL said he was suggesting that there was a certain modicum of truth in both views. The surfaces were amorphous.

Dr. HATFIELD remarked that one could have cold-working effects without presumably entering the field of condition which would produce the solution of the constituents.

Mr. GILL said that an experiment on somewhat similar lines to the one described by Dr. Trent in his paper had been described elsewhere.   A length of steel wire was severely abraded by rubbing against a fixed pulley—the experiment was conducted in a darkened room—and sufficient heat was produced momentarily to cause the region at maximum temperature to be visibly red.   A water-quench was applied at this point, and subsequently a microsection taken on a piece of the wire from this locality showed exactly the same features as were illustrated in Dr. Trent's micrographs.   Taking the results of this experiment in conjunction with those of the microscopic examination and hardness tests on numerous samples of wire exhibiting the features already described, it seemed to him that the only constituent which fulfilled all the requirements was martensite.   Dr. Trent referred to methods of overcoming the wire-rope failures caused by the phenomenon he had described and mentioned lubrication.   He (Mr. Gill) could add that he knew that the use of a much milder carbon-steel wire than the types commonly incorporated in steel wire ropes had successfully overcome this difficulty.

Mr. WHITELEY interjected that, on theory, it should not, since martensite should still be formed.

Mr. GILL stated that he could say quite definitely that the problem was overcome in the manner mentioned.

Dr. A. H. JAY (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) said that he had examined the ground surface of a steel bar (carbon 0·39%, manganese 1·66%, molybdenum 0·33%) and had found a thin layer of austenite on the outside surface. This austenitic layer would be about 0·00005–0·0001 in. thick.

Mr. J. WOOLMAN (Brown-Firth Research Laboratories, Sheffield) referred to the cause of the cracking of the wires.   Dr. Trent had said that the presence of the so-called martensitic layer did not alter the bending characteristics of the wire, but later on he said that the cracks were formed by the bending of the wires after passing over fixed pulleys.   Dr. Hatfield had mentioned that all railway tyres had cracks on the surface, which resulted from abrasion of the tyre surface either with the brake block or with the rail, and they had found effects on the tyre surface similar to what Dr. Trent had found on the wire.   They had found all degrees of heating of the surface, ranging from the tempering of the surface layers to the production of hard white-etching constituents, indicating that apparently

the material had exceeded the critical range and had subsequently been rapidly cooled. In these cases cracks formed with very little bending at all of the material. He was wondering whether the cracks which had formed on the wires were due not so much to repeated bending as to the effect of repeated heatings resulting from repeated abrasion. He did not know whether it was possible to differentiate between the two forms of cracking, but he should imagine that repeated heating was probably more responsible for the initiation of the cracks than repeated bending.

Mr. G. GLENN (Messrs. Arthur Lee & Sons, Ltd., Sheffield) said he was very sorry that in the title of the paper the author had used the words " martensite on the surface of rope wire." He would have been better pleased if he had spoken of " frictional hardenite." He asked if Dr. Trent had actually etched up martensite with martensitic markings on these surface layers, or if he had just got the white etching only. If so, it was not martensite. He thought that if, as Dr. Hatfield had suggested, Dr. Trent would make some hardness tests on the white layer he would find its hardness much lower than he would have done if he had examined the same steel after quenching and tempering it at 250° C.

Mr. Glenn, illustrating on the blackboard what was obtained in such cases with a longitudinal section of wire, said it was not a layer of martensite but austenite plus something else of a much softer nature than martensite.

Apart from that, the paper was a very good one. The subject was not by any means new. It had been a bone of contention between mining engineers and the people who had manufactured wire ropes for haulage, such as were used for tramways on the Portobello line at Edinburgh and that district, where they had always had this trouble; they had always got frictional hardenite by going over fixed pulleys, &c. Even lowering the carbon content of the wire used for haulage ropes did not remedy the trouble; it only delayed the formation of frictional hardenite, and this latter came into evidence again later on in the life of the wire rope.

AUTHOR'S REPLY.

The AUTHOR, in reply, wished to thank those who had contributed to the discussion. In reply to Mr. Whiteley and Mr. Woodhead, who suggested that nitrogen played a part in the formation of the brittle layers, there were a number of objections to this point of view : (1) Owing to the extremely rapid rate at which these layers could be formed (as shown in the laboratory tests using the Izod pendulum as a striker), it would be necessary to postulate an enormously rapid rate of diffusion for the nitrogen. (2) The author had tempered martensitic layers at temperatures up to Ac_1 and

above without discovering any trace of braunite or nitride needles; the structure formed was sorbite of a fine particle size, which became resolvable at the higher temperatures. (3) The needles in Fig. 14 were not nitride needles, since, as the author had pointed out on p. 407 P of the paper,[1] the number of these needles could be multiplied by the application of cold-work until the whole structure consisted of an interlacing mass of needles. It was largely because of this evidence that it was concluded that this particular structure consisted of martensite needles in austenite.

Dr. Hatfield and others had questioned whether the embrittled layers were really martensitic in structure. First, it was suggested that hardness tests should have been carried out. The author agreed that this would have been desirable, but it was considered that the hardness tests were not the sole criterion of martensite, and in this case they would not be a very reliable criterion. This was because the martensitic layers observed at that time were not more than 0·003 in. thick, covered only part of the worn surface and were very uneven in thickness. Without sectioning the wire it was impossible to estimate the thickness of the martensite at any point. Thus, hardness tests on the wire surface would be influenced by the softer sorbitic steel beneath the martensite and would be lower than the correct figure. As an instance, Mr. Gill quoted hardness figures of 600 Vickers, which was probably lower than the true hardness of the martensitic surface and led Dr. Hatfield to question whether this figure supported the theory that the wires were martensitic.

The author had subsequently examined a rope which had been subjected to extremely severe abrasion. On the abraded surfaces a martensitic layer 0·006 in. thick and of fairly even thickness was observed. Hardness tests on the surfaces after polishing with 00 emery gave an average hardness number of 820, using a 5-kg. load on the Vickers hardness machine. A length of the same wire was quenched in water from red heat and showed a martensitic structure. The average hardness under the same testing conditions was 796. The closeness of these figures confirmed that the layer on the wire was martensitic.

The fact that these layers etched nearly white in colour and did not show the characteristic martensite needles could be explained by the extremely short time during which the layer was above the Ar_1 point, which would give the layer an extremely small grain size. With regard to the suggestion that the layer was amorphous, the author considered that this was answered by Dr. Quarrel, who pointed out that electron-diffraction had shown that amorphous layers existed on metals but in thicknesses of 50 Å., not visible under the microscope and of a much smaller order than those of the layers here discussed.

Dr. Hatfield had questioned whether there was sufficient bulk

[1] *Journal of the Iron and Steel Institute*, 1941, No. I.

in the wires to ensure a quenching effect sufficient to retain the martensite. If one took the most extreme case, a wire 0·1 in. in dia. worn down to half its diameter, with a layer 0·005 in. thick heated to a temperature of 800° C. across the whole section, this would mean that the bulk of the wire as a whole was approximately 8 times that of the heated layer, and the heat from the layer would be sufficient to raise the whole wire to 100° C., assuming no heat loss from the surface of the wire. Actually, as a general rule the conditions were very much less severe, and, in the author's opinion, were quite capable of producing a cooling effect in the layer sufficient to retain martensite.

In stating that the layer in question was actually a martensitic layer the author was taking into account the whole of the evidence obtained from the laboratory tests and the examination of the structures formed in service, as presented in the paper.

In reply to Dr. Becker, the structure shown in Fig. 11 was not a "freak" and had been reproduced a large number of times in different specimens of rope wire. In some cases the two halves of the sheared wire were not welded together, but in nearly every case martensite was observed on the sheared surfaces.

Dr. Becker's remarks on the formation of martensitic layers due to electrical discharge from the surface and by the burnishing action of fine grinding wheels were very interesting. The author's experience had shown that martensitic surfaces were definitely formed by friction with steel surfaces, but there was no definite evidence on the effect of friction between the rope and stone surfaces, though this frequently occurred with haulage ropes.

The author agreed with Professor Andrew that some austenite might be retained with the martensite, owing to the extremely rapid rates of cooling. This should be investigated by X-ray diffraction methods. The question whether the formation of martensite was a purely thermal effect of friction or whether the mechanical distortion of the lattice structure itself played a part would afford a very useful subject for further research, but there did not seem to be sufficient evidence at the moment to answer this question. The work of Bowden and others had shown that very high surface temperatures could be obtained during friction.

In reply to Mr. Woodhead, the author had not stated in the paper that "when a wire rope went round a pulley and round a bend in the road, it probably got stretched beyond its limit of proportionality." With regard to the influence of the composition of the wire upon the tendency to form martensitic layers, particularly the influence of the manganese content and small amounts of nickel and chromium, it was intended to carry out research on this subject. For the present it had been shown that martensite occurred so frequently that its presence could not be accounted for by the accidental presence of a small amount of residual chromium. Mr. Woodhead had stated that martensite was never formed on the

wire surface during drawing.　Mr. Scholes (in the correspondence), however, had stated that this had been observed on rare occasions.

The author agreed with Mr. Woolman that repeated heating of the surface was probably more responsible for the formation of cracks in the martensitic layers than repeated bending.　This had been stated in the paper (p. 405 P).

The author regretted that, owing to illness, he had been unable to reply to the correspondence in time for earlier publication. Most of the points raised in the correspondence had been answered in the reply to the discussion above, but the author would like to take this opportunity of replying briefly to one or two further points.

He wished to thank Dr. Desch and Mr. Scholes for drawing his attention to the earlier work of Dr. Stead on this subject in 1912 and 1917, and for the further interesting evidence on the formation of martensitic surfaces which they had given.　The author had come across a case of large built-up ridges as shown in Dr. Desch's Fig. A.　They had been caused by extremely severe friction over a short period of time.　The ridges in this case consisted partly of martensitic steel from the wire, but largely of mild steel from the object against which the rope was rubbing.　All the pearlite areas in the mild steel had been converted to martensite.

Dr. Schnurmann's remarks were interesting, but did not seem greatly to affect the evidence and results recorded in the paper, except to indicate that lubrication and the condition of the immediate surface might play a considerable rôle in determining the amount of heat produced during friction.

Erratum.

THE CRYSTAL STRUCTURE OF CEMENTITE, Fe₃C.

By H. LIPSON, D.Sc., and N. J. PETCH, B.Sc., B.Met.
(CAVENDISH LABORATORY, CAMBRIDGE).

This paper was published in the *Journal of The Iron and Steel Institute*, 1940, No. II., pp. 95 P–103 P, and the correspondence on it and the authors' reply will be found on pp. 104 P–106 P of that volume.

It is regretted that in the Table of the details of the X-ray pattern of cementite given in the reply (*loc. cit.*, p. 106 P) the line positions are wrongly recorded; in the calculation a mistake was made which resulted in a systematic error in the values of sin θ of the order of 2%.

The correct Table is as follows :

TABLE A.—*Observed Positions and Intensities of Lines in the X-Ray Pattern of Cementite, Fe₃C, taken with Co Kₐ Radiation.*

Sin θ.	Intensity.	Indices.	Sin θ.	Intensity.	Indices.
0·3517	1·0	0 2 0	0·4524	12·6	2 1 1
0·3751	14·4	1 1 2, 0 2 1	0·4779	7·2	1 1 3
0·3951	6·3	2 0 0	0·4829	9·2	1 2 2
0·4032	5·8	1 2 0	0·5075	3·8	2 1 2
0·4246	14·2	1 2 1	0·5312	3·8	0 0 4, 0 2 3
0·4323	15·6	2 1 0	0·5450	1·6	2 2 1
0·4410	14·2	0 2 2	0·5637	4·5	1 3 0
0·4446	23·2	1 0 3			

OBITUARY.

ALBERT ORLANDO PEECH died on March 22, 1941, after a short illness; he was in his sixty-ninth year. Throughout the whole of his business career he was closely connected with many branches of the British iron and steel industry. He was one of the proprietors of the family business of Messrs. Steel, Peech and Tozer, of Sheffield, a connection which lasted for fifty years. This concern became the parent of The United Steel Companies, Ltd., and in the formation of this group Mr. Peech was associated with the late Mr. Henry Steel; he was its chairman from 1920 to 1928. His other business activities included the chairmanship of the Templeborough Rolling Mills, Ltd., and directorships of the Appleby-Frodingham Steel Co., Ltd., the British Iron and Steel Corporation, Ltd., Davy and United Engineering Co., Ltd., the Hoffmann Manufacturing Co., Ltd., Messrs. Owen and Dyson, Ltd., the Refractory Brick Company of England, Messrs. Robert Stephenson and Hawthorns, Ltd., the Steetley Lime and Basic Co., Ltd., Tinsley Wire Industries, Ltd., and Messrs. William Cooke & Co., Ltd. He was president of the British Iron and Steel Federation for the period 1924–1925.

Mr. Peech was one of the best known members of the industry; his shrewd advice, given in the fewest words, was seldom at fault. A somewhat diffident manner cloaked wide experience and much kindly joy in life. Good fellowship in the company of contemporaries and helpful encouragement to those who were younger ensured to him a wide circle of friends.

Mr. Peech became a Member of The Iron and Steel Institute in 1918; in 1927 he was made a Member of Council and in 1937 he was elected a Vice-President.

CHARLES JOHN WALSH died suddenly on February 22, 1941, at his home, the Old Rectory, Babworth, Retford. He was fifty-six years old. Born at Birmingham, he was educated at a school in Aston, and afterwards studied metallurgy at Birmingham Technical College. His career began with his entry into the firm of Messrs. John Walsh & Co., iron and steel merchants, Birmingham. Soon afterwards he was appointed a director of the Giles Foundry Co., Ltd. In 1909 he joined the board of the New Conveyor Co., Ltd., Smethwick, of which he subsequently became chairman. Two years later, relinquishing his interests in Messrs. John Walsh & Co., he went to Sheffield to become first general manager and then managing director of Messrs. Ibbotson Bros. & Co., Ltd., Globe Steel Works, Sheffield. In 1932 he joined the staff of The United Steel Com-

panies, Ltd. Two years later he became managing director of the Frodingham Iron and Steel Co., Ltd., and of the Appleby Iron Co., Ltd. When in October, 1934, those concerns were amalgamated to form the Appleby-Frodingham Steel Co., Ltd., he became a director and general manager of the new company. In 1938 he was appointed assistant managing director of The United Steel Companies, Ltd., and in September, 1939, managing director. Mr. Walsh was also on the board of directors of Messrs. Samuel Fox & Co., Ltd., of Messrs. Steel, Peech and Tozer, of the Workington Iron and Steel Co., Ltd., of Messrs. Owen and Dyson, Ltd., and of the North Lincolnshire Iron Co., Ltd. In 1933, while he was in Sheffield, he was elected Master Cutler.

Mr. Walsh became a Member of The Iron and Steel Institute in 1912, and in November, 1939, he was elected a Member of Council. He had previously served as an Hon. Member of Council during his presidency of the Lincolnshire Iron and Steel Institute in 1938–1939.

JAMES BOYD ALLAN died on January 2, 1941, at Prestwick, Ayrshire, aged eighty-three. He started his employment with Messrs. David Colville & Sons, Ltd., over fifty years ago, as the testing superintendent of their Dalzell Works, Motherwell. In 1901 he was appointed secretary of the company and later a director. In 1916 he became managing director and vice-chairman, which positions he held until his retirement in 1931, when the amalgamation of his firm with Messrs. James Dunlop & Co., Ltd., took place under the title of Messrs. Colvilles, Ltd. He had also been managing director of Messrs. Archibald Russell, Ltd., colliery owners, Glasgow. Mr. Allan joined The Iron and Steel Institute in 1917.

JOHN BOTCHERBY ALLAN, manager of the foundry department of the Staveley Coal and Iron Co., Ltd., died at Chesterfield on February 13, 1941, being fifty-two years of age. He was born at Newcastle-upon-Tyne and, after graduation, received his engineering training in his native town at the St. Peter's Works of Messrs. R. and W. Hawthorn, Leslie & Co., Ltd. Later he joined the staff of Messrs. Cammel Laird & Co., Ltd., Sheffield, where his father, the late Mr. J. M. Allan, was managing director. During the last war he was responsible for the shell department of these works, which he had organised under his father's direction. After the war he was appointed general manager of the Grimethorpe Works, and on their amalgamation with Messrs. Vickers, Ltd., he joined the English Steel Corporation, Ltd., with whom he remained until his appointment with the Staveley Company.

Mr. Allan was a strong supporter of all efforts directed towards the standardisation of foundry products and raw materials. He was a prominent member of the Institute of British Foundrymen and took a very active part in the conduct of the British Cast Iron Research Association. He joined The Iron and Steel Institute in 1921.

MATTHEW S. BIRKETT, O.B.E., died on August 6, 1941, after a very short illness. He began his career by entering the Civil Service (Census Office) in 1901, and became private secretary to Sir Bernard Mallet, K.C.B., Registrar General. At the outbreak of the last war he was seconded for special statistical enquiries to the Ministry of Labour, and, on the formation of the Ministry of Munitions, joined that department to become Assistant Controller of Munition Statistics. At the same time he was secretary of a departmental committee of investigation into the statistical methods of the different departments of the Ministry, and also secretary of the Statistical Conference, which co-ordinated the whole of the statistics of the Ministry. In recognition of his services during the war, he was awarded the O.B.E. in 1919. In the same year he was appointed statistical officer of the National Federation of Iron and Steel Manufacturers, of which he became secretary in 1926. He held that post until 1935, when, on the reorganisation of the Federation, he became assistant to the chairman and director (later, assistant to the directors) of the British Iron and Steel Federation. Mr. Birkett was a Fellow of the Royal Statistical and Royal Economic Societies. He was elected a Member of The Iron and Steel Institute in 1920.

BERNARD CLASEN died on July 12, 1941, at Harrogate. Born and educated in Luxemburg, he came to England at the age of twenty-five. Until the outbreak of the last war he represented and directed commercial interests of the German Steelworks Syndicate and controlled a large proportion of the steel imported into Britain from the Continent. Early in 1914 he was invited to return to Luxemburg to organise the sales of A.R.B.E.D., the most important steel-producing concern of that country. After the war he became the founder and first managing director of the Columeta Export Co., Ltd. Then followed a period of intense activity and travel, establishing this organisation and its branches throughout the world. In the following years Mr. Clasen played an important rôle in the evolution and development of the various international steel associations. Apart from his business activities he held the office of Consul General of Luxemburg. His services to international trade were recognised by Luxemburg, France and Belgium, from which countries he received high honours.

Mr. Clasen took a great interest in the activities of The Iron and Steel Institute during all the long years of his membership—he was elected in 1912; in particular he was frequently to be seen at Autumn Meetings held on the Continent, and he gave very valuable assistance in organising the Institute's meeting held in Luxemburg in 1934.

HENRY HERBERT COLDWELL-HORSFALL died on April 2, 1941, at his home, Penns Hall, Erdington, at the age of eighty-four. He was the step-son of the late Mr. James Horsfall, the inventor of " patented

wire," who was a partner of the firm of Messrs. Webster and Horsfall. The firm had been founded as early as 1720, when John Webster converted an iron forge into a wire mill, and it was a descendant of his, Joseph Webster, who produced the first steel music wire in 1824 ; in the improvement of this material he had the help of Mr. Horsfall, whom he took into partnership in 1855. At the age of eighteen Mr. Coldwell-Horsfall joined the firm, and in 1886 he became manager, which post he held until the firm was amalgamated, in 1891, with Messrs. Latch and Batchelor, Ltd., of Hay Mills, Birmingham. He became chairman of the amalgamated firms, and later joint managing director, a position which he held till his death. Mr. Coldwell-Horsfall was for many years a Member of The Iron and Steel Institute, his election having taken place in 1899.

THOMAS GIFFORD ELLIOT died suddenly on May 25, 1941, at his home, Hillcote, Park Edge, Hathersage, Derbyshire. He was sixty-seven years of age. He had been on the research staff of Messrs. Hadfields, Ltd., for nearly forty years, of which firm he had been chief chemist for a long period. In the course of his career Mr. Elliot published numerous papers ; the following were submitted to The Iron and Steel Institute : " Volumetric Estimation of Sulphur in Iron and Steel " (1911) and " On Photomicrographs of Steel Sections " (1920), and he frequently made valuable contributions to the discussion of papers published by the Institute. Mr. Elliot was elected a Member of The Iron and Steel Institute in 1912.

JOHN GUNTER FAIRGRIEVE died at his home at Cambuslang on July 23, 1941. He had been with Messrs. Colvilles, Ltd., since 1919 ; at first he held the post of chief chemist, and was later transferred to the melting department of the Clydebridge Works to become assistant works manager.

Mr. Fairgrieve served on the Ingot Moulds Sub-Committee of the Committee on the Heterogeneity of Steel Ingots of The Iron and Steel Institute and The British Iron and Steel Federation. He contributed a paper on " Basic Open-Hearth Practice in Scotland " to the Symposium on Steelmaking published by the Institute in 1938. He was elected a Member of The Iron and Steel Institute in 1928.

ALVIN IRWIN FINDLEY died on December 12, 1940, at St. Petersburg, Fla., U.S.A., where he had spent his winters since his retirement in 1930. He was born in 1859 at Monmouth, Illinois, and acquired his early education at the Acron Public School and at Buchtel College, after which he spent two years as city editor of the Acron " Daily Beacon " before entering the College of Wooster, Ohio, where he obtained the degrees of A.B. and A.M. in 1881 and 1886, respectively. In the following years he was working on the editorial staff of the Chicago " Interior " and the Philadelphia

" Press," and later returned to Acron as associate editor of the " Daily Beacon." From 1892 to 1905 he was editor of " The Iron Trade Review of Cleveland," now known as " Steel," and was vice-president of the Iron Trade Review Company. He left that paper in 1905 to become associate editor of " The Iron Age," of which he became editor six years later. During his career Mr. Findley contributed many articles on iron and steel to the technical and daily press, and became a member of numerous technical societies. He joined The Iron and Steel Institute in 1920.

FREDERICK WILLIAM FIRTH died on November 14, 1941, at Sheffield, aged sixty-four. He joined The Brightside Foundry and Engineering Co., Ltd., in his early youth, soon after leaving school, and the whole of his active life was spent in its service. After some years of training he became a director of the firm, and in 1925 he succeeded his brother, the late Mr. T. H. Firth, as chairman. He played a leading rôle in bringing the company into the forefront in heavy foundry work as well as engineering, especially in connection with modern systems of air-conditioning and heating of public buildings. Mr. Firth was also a director of Messrs. Moorwoods, Ltd. He was a member of the Institute of British Foundrymen and a Past-President of the Sheffield branch of that Institute. He was elected a Member of The Iron and Steel Institute in 1918.

WILLIAM TREFOR MORGAN died on February 1, 1941, at Rochester, N.Y., aged forty-six. Born on May 27, 1895, in Swansea, he received his technical education at Swansea Technical College and Sheffield University. His studies were interrupted by the last war, however, in which he saw active service for four years in France, Egypt and Palestine. After the war he took up employment with Messrs. Richard Thomas & Co., Ltd., and then joined the research staff of the Admiralty. Six years later he went to America, where he was first associated with Messrs. Babcock and Wilcox, of Bayonne, N.J. In 1929 he was appointed chief metallurgist of the Taylor Instrument Companies, which position he held at the time of his death. Mr. Morgan was elected a Member of The Iron and Steel Institute in 1930.

CHRISTER PETER SANDBERG, C.B.E., the senior partner of Messrs. Sandberg, Consulting and Inspecting Engineers, died on June 26, 1941, at his home, West House, Crockham Hill, near Edenbridge, Kent. Born on August 11, 1876, he received his education at Dulwich College, at the Crystal Palace School of Engineering and at University College, London. In 1894 he commenced a pupilage of four years, the latter part of which he spent under his father, the late Mr. C. P. Sandberg, who in 1868 had founded the firm that bore his name.

In addition to other consulting engineering work, the firm

specialised in metallurgical problems, and, in particular, became associated with processes for improving the wearing capacity and soundness of steel railway rails. To this work Mr. Sandberg's first important contribution was his patent, taken out in 1914, for the heat treatment of rails by the process now well known as the " Sandberg sorbitic process." During the last war Mr. Sandberg gave the use of this process to the British Government free of all royalties. A further war development was the sorbitic treatment of tramway rails *in situ*, which temporarily overcame the difficulties of replacement due to the shortage of steel and labour. Seven hundred miles of tramway track were treated in this way.

A further development of great importance for which Mr. Sandberg and his two brothers were responsible resulted in the patenting in 1928 of the Sandberg oven for controlling the cooling of rails through that range of temperature in which internal fissures are likely to develop after manufacture. The oven effected a complete cure, and the benefits of controlled cooling are now generally recognised, so that it has become the standard practice of British railways and is also in almost universal use in the United States. In addition, various other track details, including a steel sleeper, were the subject of the Sandberg interest.

It is also worthy of note, as indicating Mr. Sandberg's wide range of interests, that it was due to his initiation of the idea and his determination and perseverance, that the cargo of gold and silver of a value of over a million pounds was recovered from the *S.S. Egypt*, which sank off Ushant in 1922.

In addition to doing inspection work for certain British railways, Mr. Sandberg acted as Consulting and Inspecting Engineer for the Chinese Government Railways, the Royal State Railways of Siam and a number of Colonial railways. Mr. Sandberg was also Chairman of The Sheffield Testing Works, Ltd., British and Dominions Feralloy, Ltd., and Associated Transmissions, Ltd.

For his services during the last war Mr. Sandberg was made a C.B.E. in 1920. In 1922 he was made a Commander of the Chinese Order of Chia Ho and in 1925 a Commander of the Siamese Order of the White Elephant. He became an Associate Member of The Institution of Civil Engineers in 1902 and a Member in 1918. Mr. Sandberg was elected a Member of The Iron and Steel Institute in 1898.

NILS EDWARD FORBES SANDBERG died on March 10, 1941, at the early age of thirty-three; he was killed in a motor accident while engaged on civil defence work. The second son of the late Mr. C. Peter Sandberg, C.B.E., he was educated at Harrow. On leaving school he went through a course of practical training at the Cargo Fleet Iron Co., Ltd., and the Workington Iron and Steel Co., Ltd. He was made a partner in Messrs. Sandberg in July, 1939. He joined The Iron and Steel Institute in 1937.

VICTOR STOBIE died on December 31, 1940. Born in Birmingham, he was the son of the late Mr. Thomas Stobie, who for many years was a foreign representative of Messrs. Thomas Firth & Sons, Ltd., of Sheffield, and it thus happened that he spent his childhood and youth in Paris. In the beginning of the century he came to Sheffield, where he occupied a junior position with Messrs. Hobson Houghton & Co., Ltd. At the same time he carried on an agency business for a foreign refractory brick firm. In 1910 he founded the Sheffield Annealing Works Company. The furnace of the producer-gas-fired " coffin " type used there was designed by himself, and he succeeded in selling a number of similar installations to German and American works. At that time considerable quantities of high-speed steel mill scale were accumulating in Sheffield, and he realised that it would be profitable to extract the tungsten contained in it and that this could be done by the use of the electric furnace. Thus, in 1912 he sold his annealing works and moved to Dunston-on-Tyne, where he founded the firm known as the Stobie Steel Company. The electric furnaces that he installed there were based on his own patents. During the last war he got his works into full production, and found time, in addition, to study the production of synthetic white iron by a duplex process employing a pair of stationary electric furnaces. During the same period he designed and patented an electrode economiser for the elimination of the so-called chimney effect, and supplied several British steelworks with electric furnaces. Shortly after the war the Dunston Works were shut down and he devoted much time and energy to the development of a high-frequency melting furnace, which was later installed in several works.

Mr. Stobie was a member of the Institution of Electrical Engineers. He also interested himself in the activities of the Institute of British Foundrymen and was elected President of that body in 1932. He joined The Iron and Steel Institute as early as 1905.

JOHN STANLEY TYZACK died on November 15, 1941, at his home, Carlton, Notts., aged sixty-four. His father, the late Mr. W. A. Tyzack, had founded the firm of Messrs. W. A. Tyzack, Ltd., high-speed steel manufacturers, and he entered the concern as a young man. In later years he became chairman and governing director of the company. He joined The Iron and Steel Institute in 1933.

Dr. JOSEPH WARD died on July 7, 1941, at his home, Endcliffe Grange, Sheffield. He was born in 1864 and educated at Sheffield. As a boy of fourteen he joined his elder brother, the late Mr. T. W. Ward, who was the founder of the firm of coal, metal and machinery merchants now known as Messrs. T. W. Ward, Ltd. In 1889 he was taken into partnership, and in 1904, when the firm was incorporated as a limited company, he was appointed joint managing director. He was made chairman of the concern in 1919, a position

which he held until his death.   He took a leading part in the forma-
tion of the Ketton Portland Cement Co., Ltd., of which he was
chairman and managing director.   In addition, he was chairman of
Ribblesdale Cement, Ltd., Messrs. Thomas Smith & Sons (Rodley),
Ltd., The Midland Iron Co., Ltd., Messrs. Marshall, Sons & Co.
(Successors), Ltd., and many of the subsidiary and associated com-
panies of Messrs. T. W. Ward, Ltd.   His long experience in the iron
and steel trade, especially in connection with scrap metal and ship-
breaking, earned for Dr. Ward a place as one of the leading authori-
ties on those subjects.   During the last war he served in an advisory
capacity on questions of iron and steel scrap to the Ministry of
Munitions.   He was made a Justice of the Peace in 1922 and elected
Master Cutler in 1931.   In 1939 the honorary degree of LL.D.
(Sheffield) was conferred upon him in recognition of his services to
the University in his capacity as chairman of the Applied Science
Department.   Dr. Ward was elected a Member of The Iron and Steel
Institute in 1912.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

CONTENTS.

The Editor has been assisted in the preparation of this Survey by
R. A. RONNEBECK.

REFRACTORY MATERIALS

Slag Action of Alkalies on Refractories. T. L. Hurst. (Industrial Heating, 1941, vol. 8, Jan., pp. 72–81). The author's paper on the action of vapours from potassium and sodium salts in promoting the slagging of refractory bricks is reproduced. (*See* Journ. I. and S.I., 1940, No. II., p. 206 A).

Blast-Furnace Brick of New Design. (Blast Furnace and Steel Plant, 1941, vol. 29, Feb., pp. 187–188). A description is given of a new wedge-shaped blast-furnace refractory brick, known as the " Agnew Design," which has recently been introduced in the United States. The brick is made in two lengths, namely, 9 in. and $13\frac{1}{2}$ in. The section perpendicular to the long axis is not a rectangle but a parallelogram, measuring approximately 3 in. and 6 in. between the opposite faces. The bricks are made as " rights " and " lefts," in four sizes for each, with different degrees of taper, so that linings of any diameter in the range 10–38 ft. can be built. In constructing a lining the bricks are laid with the 3-in. side down and the small end towards the centre. Each course is therefore 6 in. high, and the courses are laid alternately with " lefts " and " rights." The number of continuous horizontal joints is thus reduced and there are no continuous vertical joints at all. A much greater mechanical strength and a saving in the amount of mortar required are among the advantages claimed for this brick.

FUEL

A Consideration of the Combustion Turbine Problem. B. Weissenberg. (Stahl und Eisen, 1941, vol. 61, Mar. 27, pp. 305–313). The author discusses the heat balance and efficiency of combustion turbines and the industrial and economic conditions which lend themselves to this form of power production.

Combustion Control for Multi-Fuel Furnaces. (Blast Furnace and Steel Plant, 1941, vol. 29, Feb., pp. 189–192). A detailed description is given of the Republic-Smoot combustion control system, which can be used for the automatic control of fuel to open-hearth and other industrial furnaces heated by more than one fuel. Particulars are given of an installation controlling a 90-ton open-hearth furnace fired with fuel oil and coke-oven gas. The system is designed to maintain accurately the supply of air for combustion at any desired proportion to the sum of the flows of the two fuels being burned. It also keeps the furnace pressure constant at any predetermined value.

War-Time Output of Rolled Metal Has Demanded Accurate Sheet-Metal Control Equipment. H. J. Smith. (Sheet Metal Industries, 1941, vol. 15, Mar., pp. 312–319, 326). The author describes some modern control instruments and systems for the process-control of gas producers, open-hearth furnaces, soaking pits, waste-heat boilers, rolling processes and heat-treatment furnaces.

Large Central Coal-Washing Plant. (Iron and Coal Trades Review, 1941, vol. 142, Apr. 25, pp. 461–463). A detailed and illustrated description is given of a coal-washing plant recently erected in Scotland to treat all coals 3 in. and under supplied by a group of five mines. The plant, which is capable of handling 140 tons of raw coal per hr., is so designed that, depending on its characteristics, the coal can be either washed in a single wash-box, or washed and re-treated in a second wash-box. An absolutely closed water circuit is maintained and no dirty effluent passes from the plant.

Thermodynamic Treatment of the Swelling Pressure of Coal. W. Fuchs. (Journal of the Franklin Institute, 1941, vol. 231, Feb., pp. 103–119). The author attempts a theoretical treatment of the swelling pressure exerted by coal during carbonisation, and derives formulæ for calculating this pressure from the first and second laws of thermodynamics.

PRODUCTION OF IRON

Principles for Determining Production Capacity and Their Application in the Iron and Steel and Related Industries. H. Euler. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Oct., pp. 187–202). Taking as a basis production in a unit of time, the author studies the influence of input, production process, output, scrap, material in circulation and losses on the magnitude of production. He thus applies these general influences to the particular aspect of production in blast-furnaces, open-hearth furnaces and Bessemer converters and rolling-mills.

Twentieth-Century Steel-Mill Progress. D. L. Mekeel. (Blast Furnace and Steel Plant, 1941, vol. 29, Jan., pp. 35–39, 50). The author briefly surveys the developments which have taken place in the United States during the last forty years in coke-oven practice, blast-furnace and steel furnaces, rolling-mills and rolling-mill power-stations.

Production of Ferro-Manganese. (Electrician, 1941, vol. 126, Mar. 28, pp. 191–192). The production of 80% ferro-manganese in electric furnaces is discussed, and particulars are given of a sealed vertical electric furnace and of the relative current consumptions per ton of product in 400- and 4000-kW. furnaces.

Historical Investigations of the Heavy Iron Industry of Rhenish Westphalia. F. Hellwig. (Stahl und Eisen, 1941, vol. 61, Feb. 13, pp. 153–164). The author discusses the various sources of information available for studying the history of the development of the heavy iron and steel industry of Rhenish Westphalia.

FOUNDRY PRACTICE

Melting and Casting Problems in the Production of High-Strength and Special-Duty Alloy Iron Castings. A. E. McRae Smith. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 64, Mar. 20, pp. 191–193 ; Mar. 27, pp. 203–204, 212). The author describes the cupola process for the production of high-strength cast irons with physical properties in excess of the minima laid down for Grade III. iron in British Standard Specification 786. He pays particular attention to the selection of suitable steel scrap, the attainment of high tapping temperatures and the tapping technique. He shows how an addition of molybdenum, preferably in conjunction with nickel, functions in the production of an acicular structure in cast iron with a carbon content of 2·6–2·9%. Phosphorus has a very marked influence on the structure of this iron, and may cause the formation of laminated pearlite instead of acicular pearlite if over 0·15% is present in straight molybdenum irons. To illustrate the effect of phosphorus on the mechanical properties of Grade II. and Grade III. irons of the above specification, the author presents curves showing the tensile strength and impact value in relation to the phosphorus content. From these it is seen that for Grade II. iron there is little loss in tensile strength with phosphorus up to 0·6%, but considerable reduction in the impact value. In a nickel-molybdenum Grade III. iron there is a sharp drop in impact value on passing from 0·1% to 0·2% of phosphorus, which is almost certainly due to the substitution of pearlite for the shock-resisting acicular structure. In the case of Grade III. pearlitic irons (without molybdenum), there is no reason to suppose that such a sharp change in impact strength would occur ; the optimum phosphorus content for the acicular nickel-molybdenum type of iron would appear to be 0·1%.

Cupola-Melted Blackheart Malleable Castings. V. N. Wood. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 64, Mar. 20, pp. 187–188 ; Mar. 27, pp. 205–206). The author gives a detailed description of the two main processes involved in the production of blackheart malleable iron castings, namely, the production of the iron in the cupola and the annealing of the iron in sealed pots. He explains and illustrates with micrographs the structural changes which take place during the annealing.

Design of Malleable Iron Castings. J. H. Lansing. (American Foundrymen's Association : Foundry, 1941, vol. 69, Jan., pp. 41, 119). In a brief discussion of the design of malleable iron castings, the author lays stress on the importance of having a knowledge of the casting technique and thus being able to assist the foundryman in producing a casting with the requisite properties.

The Application of External Chills in the Production of Steel Castings. W. F. McKee. (Transactions of the American Foundrymen's Association, 1941, vol. 48, June, pp. 735–757). The author discusses the use of external chills in making cast-steel pipe fittings for oil refineries. He also reports on an investigation of the influence of the position, section, area of contact and mass of the chill. In order to study these factors, several series of castings were made representing differently shaped joints made of square bars 3 in. × 3 in. × 18 in. long. The shape of the joints approximated to that of the letters L, T, V, X and Y. The castings were examined by cutting off the long arms and sectioning and etching the joint. The results are given in great detail, with many illustrations, and it is shown that the shape of a chill should never be such as to form re-entrant angles of sand at its sides or ends except when it is desired to retard the chilling effect, and that, when chills are used at junctions, the radius at the root of the angle formed by the arms should be at least one-third, but less than one-half, of the section thickness.

A Sand Control Program in a Malleable Foundry. D. F. Sawtelle. (Transactions of the American Foundrymen's Association, 1941, vol. 48, June, pp. 723–732). The author describes the methods adopted at an American foundry for the closer control of the properties of the moulding sand, and how the benefits to be obtained by applying the results of laboratory tests were demonstrated to the moulders.

Sand Control in the British Foundry Industry. J. J. Sheehan. (Transactions of the American Foundrymen's Association, 1941, vol. 48, June, pp. 766–773). The author describes how research on moulding sands is organised in Great Britain, and compares this with the American research organisation.

Rope Pulleys. J. R. Webster. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 64, Apr. 3, pp. 225–227). The author gives a detailed description of the moulding technique employed for casting a cast-iron rope pulley, 9 ft. 10 in. in dia., with 17 grooves, weighing about 5 tons. Some difficulty was experienced in making the correct contraction allowance, as the casting did not contract according to rule. Experience gained in casting pulleys of about this size has shown that the correct contraction allowance with loam moulds is $\frac{1}{20}$ in. per ft., whereas with the inside of green sand the usual allowance of $\frac{1}{10}$ in. per ft. is correct.

PRODUCTION OF STEEL

Air and Gas Reversing Valves. W. Trinks. (Iron and Steel, 1941, vol. 14, Mar., pp. 207–208). The author discusses the influence of the design of the gas-reversing valves on the operation and output of the open-hearth furnace. He explains why " sharp working " open-hearth furnaces cannot be built unless large inlet and outlet valves with very little resistance to the flow of gas are used in conjunction with a tall stack, and unless the regenerators are kept perfectly gas-tight. By " sharp working " is meant a furnace into which the gas and air flow at high velocity with a cutting flame. In conclusion the author describes a water-cooled slide or gate valve made of a low-carbon steel of a design which has given excellent service.

The Use of Chromium in Steel Production. I. The Oxidation Loss of Chromium in Basic Open-Hearth Furnaces. M. Hauck. (Stahl und Eisen, 1941, vol. 61, Feb. 27, pp. 201–202). The author reports on an investigation of the factors influencing the chromium losses in the production of low-alloy chromium and nickel-chromium steels containing 0·1–0·4% of carbon. The steels were produced in basic open-hearth furnaces of 15 and 20 tons capacity. The amount of slag was kept practically constant at about 12% of the amount of steel. The lowest chromium loss occurred with chromium-nickel steels containing 0·2–0·4% of carbon ; next came chromium-nickel case-hardening steels with 0·10–0·17% of carbon, and the greatest loss was experienced with the chromium case-hardening steels with 0·10–0·15% of carbon. The author presents graphs which show the effects of the lime/silica ratio before adding ferro-chromium and of the percentage of chromium in the slag on the relation between the chromium in the steel produced to that in the ferro-chromium addition. Additional curves show how the time which elapses between adding the ferro-chromium and tapping influences the amount of chromium passing into the slag.

The Use of Chromium in Steel Production. II. The Behaviour of Chromium in Basic Open-Hearth Furnaces. G. Rockrohr. (Stahl und Eisen, 1941, vol. 61, Feb. 27, pp. 203–208). The author first describes a rapid method of determining the chromium in steel-bath samples during the production of chromium steel. Determinations can be made in 8–12 min. by this method, and its introduction in German practice greatly increased the frequency with which heats of steel containing the desired chromium content could be produced in basic open-hearth furnaces. In the remainder of the paper the author studies the rate of oxidation of that chromium which is in the charge before making ferro-chromium additions and the effects of the basicity of the slag, the iron content of the slag, the carbon content of the steel and the total quantity and propor-

tion of the slag drawn off, on the chromium losses. The results of numerous tests are shown in several series of graphs. From these the author concludes that attention must be given to the following points in order to reduce the chromium losses to a minimum : (1) Large quantities of chromium in the charge, especially scrap high in chromium, should be avoided ; the best results are obtained when the charge contains 0·4–0·6% of chromium. (2) The lime/silica ratio must be adjusted so that good reducing conditions prevail during the heat. (3) There should not be a large amount of slag, and its basicity should not be less than 2·0–2·2. (4) After a period of good reducing conditions, part of the slag should be drawn off shortly before adding the ferro-chromium. (5) The amount of the ferro-chromium addition should be calculated from the chromium determinations made as the melt proceeds, having regard to the condition of the heat. (6) The ferro-chromium should be preheated if the bath temperature is rather low and the amount to be added is large. (7) The period from making the ferro-chromium addition to tapping should be determined so that sufficient time is allowed for the addition to be absorbed, but the time from absorption to tapping should be short.

Electric Arc Furnace Policy. N. F. Dufty. (British Steelmaker, 1941, vol. 7, May, pp. 100–101). The author discusses the advantages of producing steel in war-time and in the post-war period by the duplex process, and describes how the problem of synchronisation could be overcome by installing arc furnaces in large open-hearth or Bessemer shops. The example cited is that of a plant consisting of a 1500-ton metal mixer and five 200-ton tilting furnaces working the Talbot process. He suggests that three 30-ton arc furnaces could work economically with such a plant. The power supply for two of these would be sufficient for refining hot metal only, whilst the third would have sufficient transformer capacity to enable it to melt a cold charge in 3 hr. This third furnace could also be used when sufficient crop ends and turnings had accumulated. The flexibility of such an installation would be valuable in the event of air-raid damage during the war, and also during peace to meet the changing requirements of customers.

The Vacuum Treatment of Molten Steel. C. G. Carlsson. (Jernkontorets Annaler, 1940, vol. 124, No. 12, pp. 686–690). (In Swedish). The author reviews the literature on the degasification of steel by melting under a vacuum. The only large-scale attempts to treat steel by this technique were made at Hanau, Germany, where, in 1933, there were one 40-kg., one 500-kg., one 650-kg., and two 4000-kg. electric induction furnaces, all with ring-shaped baths. Tests with the 4000-kg. furnaces showed that 2–5 hr. treatment was necessary to remove the gases. Attempts to shorten this by using more powerful pumps to increase the vacuum resulted in a very violent boiling of the melt.

FORGING, STAMPING AND DRAWING

Centralised Compressed Air Supply for Iron and Steelworks. W. Garski. (Stahl und Eisen, 1941, vol. 61, Feb. 6, pp. 137–141). The author compares the cost and usefulness of compressed air and steam for driving forging hammers in a steelworks. He presents calculations which demonstrate that, when converting the two media into the useful work required to drive a hammer, steam has a thermal efficiency of about 8%, whereas that of compressed air is 18%. The author also gives a detailed description of the central compressed-air supply station put in commission at the works of the Bochumer Verein in 1933.

Shell Forging. J. Malborn. (Heat Treating and Forging, 1941, vol. 27, Jan., pp. 18–19). An illustrated description is given of a 200-ton forging press for piercing billets for making shells. The press is of the vertical type, with a descending pot or die and a maximum stroke of 32 in. The hydraulic cylinder is supported on three columns, around one of which is a revolving turret. This turret can be locked in one of four positions, the first for loading the hot billet, the second for piercing, the third for removing the pierced billet and the fourth for drawing the punch or mandrel. The average monthly production of this machine is at the rate of about 270 forgings 275 mm. in dia. or 250 forgings 290 mm. in dia. shells per hr.

Controlling Metal Flow in Forging High-Explosive Shell. A. F. Macconoche. (Steel, 1941, vol. 108, Feb. 24, pp. 58–62, 92). After discussing some of the improvements in shell-forging processes which have taken place since 1917, the author describes two types of American piercing and forging machines which produce a shell forging from a billet in five operations. The interior surface of the forging does not require machining. (*See* Journ. I. and S.I., 1941, No. I., pp. 158 A and 210 A).

The Production of Valve Forgings. (Machinery, 1941, vol. 58, Apr. 10, pp. 29–32). Detailed descriptions are given of the electrical upsetting and extrusion processes for the forging of valves for internal-combustion engines. In electrical upsetting the ground blank bar is held between water-cooled copper gripping dies and is forced against a retractable copper anvil. The dies form the positive pole and the anvil the negative pole of a circuit which is completed by the bar, the current being adjusted to bring the bar up to the required temperature for upsetting. The extrusion process has been described previously (*see* Journ. I. and S.I., 1940, No. II., p. 143 A).

Modern Stamping Department in Large Automobile Plant. C. Cleveland. (Heat Treating and Forging, 1941, vol. 27, Feb., pp. 74–76). The author gives an illustrated description of the heavy stamping department of the Chrysler Corporation at Detroit, where

automobile radiator casings, mudguards, oil sumps and other parts are manufactured in large quantities.

The Deep-Drawing Testing of Sheets. H. Esser and H. Arend. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Nov., pp. 223–231). The authors make a critical survey of the following methods of testing the deep-drawing capacity of sheets of steel, copper, brass and aluminium : (1) The cylindrical-cup drawing test ; (2) the hemispherical cupping tests of Erichsen, Guillery and Sachs ; (3) the spreading-hole test of Siebel and Pomp ; and (4) a rapid drawing test of the spreading-hole type. Their object was to study the effects of the thickness of the sheet, the die clearance and the radius of the punch head on the results obtained. They found that the best results were obtained when the die clearance was 1·4 times the thickness of the sheet and the punch radius 3·0 times the sheet thickness. In their opinion the cylindrical-cup test gave a much better indication of the deep-drawing capacity than either the cupping tests or the spreading-hole technique.

The Past, Present and Future of Steel Wire Production. A. Pomp. (Stahl und Eisen, 1941, vol. 61, Mar. 13, pp. 253–256). The author reviews the development of drawing and heat-treatment processes used in the manufacture of steel wire, making numerous references to the literature on the early and recent history of the process. He also suggests some questions on which further research is necessary.

Modern Wire Manufacturing Processes in America. H. Höhle. (Stahl und Eisen, 1941, vol. 61, Mar. 13, pp. 257–265). A detailed and illustrated account is given of some modern American plant and processes for the high-speed production of steel wire. The rolling, drawing, pickling, annealing, galvanising and patenting are dealt with in separate sections.

Fine-Wire Industry. P. L. Herz. (Wire and Wire Products, 1941, vol. 16, Feb., pp. 109–114). The author discusses the problems connected with the drawing of fine wire, dealing separately with the properties of the metal of which the wire is made ; the effect of the heat generated on the wire, the die and the lubricant ; the contour of the die ; drawing machines ; and cost of production.

The Mounting of Diamonds for Use in Wire-Drawing Dies. P. Grodzinski. (Wire Industry, 1941, vol. 8, Mar., pp. 115–128). The author reviews the development of methods of mounting diamonds for wire-drawing and some of the patents governing this technique. Details are given of the types of moulds used for setting diamonds in brass, Monel metal, cast steel and nickel steel, and of the special precautions which have to be taken to conduct the heat away from the diamond during the casting process. The physical properties of industrial diamonds, sintered carbides and a number of setting metals are compared in a table.

ROLLING-MILL PRACTICE

Ingot Photography. (Steel, 1941, vol. 108, Mar. 10, pp. 75–78, 105). A photographic method of examining and recording the surface condition of hot steel ingots has been put in operation at a steelworks in Pennsylvania. The camera has a 2-in. F 1·5 lens and is placed 30 ft. away from, and 15 ft. above, the approach table to the blooming mill. From this height a photograph of two sides of the ingot together with an illuminated board is obtained; the latter shows the heat number, soaking-pit row number, size of ingot, date and other particulars. A series of eight illuminated windows of different degrees of transparency also appears on the board, and this provides a means of estimating the temperature of the ingot. It has been found best to take the picture after the ingot has received from four to ten breakdown passes. The film is developed daily, and the previous day's photographs are projected on to a 5 ft. × 7 ft. screen, and are studied by the open-hearth and mill operators, fuel engineers and metallurgists.

The Influence of the Conditions of Rolling on the Mechanical Properties, Hardness and Structure of Metal. V. P. Severdenko. (Iron and Steel, 1941, vol. 14, Apr., p. 239). An abridged English translation is presented of the author's paper which appeared originally in Metallurg, 1939, No. 9, pp. 64–67. (*See* Journ. I. and S.I., 1940, No. I., p. 286 A).

Modern Cold Strip Mill. C. A. Richardson. (Steel, 1941, vol. 108, Feb. 24, pp. 70–72). The author describes a four-stand tandem cold strip mill recently installed at the Riverdale Works of the Acme Steel Co. The mill is geared for working at a maximum speed of 2200 ft. per min., the power being supplied by a 400-h.p. motor on the first stand and a 500-h.p. motor on each of the other three stands.

Electricity Carries On! (Iron and Steel, 1941, vol. 14, Mar., pp. 202–206). Particulars and illustrations are given of improved types of electrical machinery and equipment which have been supplied to British steelworks during 1940. The machinery includes rolling-mill motors, heat-treatment furnaces and control gear.

HEAT TREATMENT

Carburizing Small Parts. R. Trautschold. (Steel, 1941, vol. 108, Mar. 3, pp. 73–76). The author describes a rotating gas-fired retort which is designed to carburise 100–150 lb. of screws or other small parts per hr. The carburising chamber consists of a cast nickel-chromium steel chamber 6 ft. long and 10 in. in inside dia. An internal spiral rib advances the work through the chamber as it

revolves at about 1 r.p.m., and longitudinal ribs tumble the small parts as they pass through the heating and carburising zones. The carburising medium is Chicago city gas, consisting of a mixture of 60–65% natural gas and 40–35% producer gas. The heat-treating equipment referred to in a previous abstract consists of furnaces of this type (*see* Journ. I. and S.I., 1941, No. I., p. 127 A).

Case-Depths in Gear Manufacture. D. McPherson. (Machinery, 1941, vol. 58, Apr. 10, pp. 37–40). The author considers the factors which influence the selection of a case-depth suitable for different applications such as gear-teeth and worm-gears, and discusses the causes of such failures as cracks and the flaking-off of the case.

Flame-Hardening Bearing Rings. J. L. Foster. (Heat Treating and Forging, 1941, vol. 27, Feb., pp. 70–71). The author describes and illustrates the flame-hardening of large bearing rings made of cast iron containing graphitic carbon 2·0–2·5%, combined carbon 0·5–0·8%, manganese 0·7–0·9%, silicon 1·5% max. and molybdenum 0·25%.

World's Largest Nitriding Furnaces Installed at Wright Aeronautical Plant. (Industrial Heating, 1941, vol. 8, Jan., pp. 24–26). An illustrated description is given of a battery of furnaces for the nitriding of aero-engine cylinders at the Paterson Works of the Wright Aeronautical Corporation. The installation consists of seven 150-kW. furnaces, and is capable of processing 2500 cylinders every 3 days. In order that the furnaces may be in almost continuous use they are mounted on rails, and each furnace can be moved between two stations, each of which is equipped with three Nichrome receptacles with a total capacity of 180 cylinders. The cycle of treatment is divided into three periods, 10 hr. for heating up, 30 hr. holding at 1000° F., and 10 hr. for the parts to cool sufficiently for the containers to be emptied. Production is expedited by moving the furnace at the end of 40 hr. over to its second station, where three more receptacles have been prepared in the meantime.

Note on the Resistance to Furnace Atmospheres of Heat-Resisting Steels. A. G. Quarrell. (Iron and Steel Institute, 1941, this Journal, Section I.). The application of the high-temperature method of electron diffraction to thin oxide films formed on a heat-resisting steel has shown that at temperatures up to 950° C. the oxide has a spinel structure. This is possessed by a large number of oxides of the general type $XO.Y_2O_3$, and is both exceedingly flexible and inherently stable. It is suggested that the oxidation resistance of heat-resisting steels is largely due to the formation of a stable spinel. Provided that such elements as nickel, chromium and aluminium are present in sufficient quantities, the spinel structure should be stabilised, and the absence of lattice changes on heating and cooling will prevent easy access of oxygen to the underlying metal surface and so greatly increase the oxidation resistance. Similarly, the fact that a number of mixed sulphides possess the spinel structure

permits of a possible explanation of the performance of heat-resisting steels in sulphurous atmospheres.

Investigation of the Suitability of the Continuous Furnace for the Annealing of Cold-Rolled Deep-Drawing Strip Steel. A. Pomp and G. Niebch. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Oct., pp. 179–186). The authors report on their investigation of the effects of annealing time and temperature and of the degree of cold-reduction on the deep-drawing properties of steel strip. They also compare the results achieved with continuous and batch annealing furnaces. The tests were made with 0·06% carbon steel strip, specimens of which were cold-reduced by 10%, 20%, 40% and 60% to a final section of 40 × 1 mm. It was observed that, after annealing for only 3 min., or even less, in the range 650–900° C. full softness was achieved and the mechanical properties were practically the same as those obtained after the customary long-time annealing. The authors describe and illustrate a specially designed continuous electric furnace and the arrangement of thermocouples with which they obtained data on the changes of temperature in the strip as it passed through the furnace. The heat input and strip speed were adjusted to give final strip temperatures of 600°, 650°, 700°, 800°, 900° C., and even higher; this necessitated strip speeds of 0·65–3·00 m. per min. Full details are given of the manner in which changes in the annealing conditions within the above limits affected the mechanical properties of lengths of steel strip of similar analysis but produced by different methods. No marked change in the properties was observed after annealing at 600° and 650° C., but after annealing at 700° C., specimens of one kind of steel had just as good properties as that subjected to the customary long-time annealing, and this was unaffected by the degree of cold-reduction. Under the same conditions the second steel had not quite such good properties as that produced by long-time annealing.

Possibilities of Modern Furnaces and Their Atmospheres in the Bright Heat-Treatment of Steel. (Sheet Metal Industries, 1941, vol. 15, Apr., pp. 483–485). The theory of the oxidising, reducing, carburising and decarburising reactions which occur between furnace gases and steel in annealing and hardening treatments are explained.

The Applicability of Salt Baths to the Patenting of Steel Wire. W. Lueg and A. Pomp. (Stahl und Eisen, 1941, vol. 61, Mar. 13, pp. 266–270). In order to ascertain whether salt baths could be used satisfactorily instead of molten lead for patenting steel wire, and thus economising in the use of lead in Germany, the authors investigated the changes in the cooling rate with temperature of steel balls immersed in salt baths of different composition. Balls about 12 mm. in dia. of a non-scaling silicon-chromium-aluminium alloy steel were prepared. These were drilled so that a thermocouple could be fixed in the centre. They were heated to temperatures between 800° and 950° C. and cooled in molten lead, potassium

nitrate, sodium nitrate and a 1 : 1 mixture of these two nitrates. The baths were held at various temperatures between 550° and 250° C. From the data thus obtained temperature/cooling-rate curves were plotted. These curves showed that, for the same initial and bath temperatures, the cooling rate in lead was greater than that in any of the salt baths, the difference being greatest in the range of sorbite formation. The effect of changes in the rate of movement of the ball in the bath was much greater in lead than in the molten salt. It was also observed that, in the case of lead baths, lowering the temperature of the bath from 550° to 350° C., thus increasing the initial difference between the temperature of the ball and that of the bath, did not affect the cooling rate. With salt baths, on the other hand, an increase in the initial temperature difference decreased the cooling rate. The authors' general conclusion was that salt baths could be used instead of lead for patenting steel wire, provided that the initial temperature difference between the wire and the bath was kept slightly greater than that for lead. Subsequent examination of the microstructure and tensile tests on lengths of steel wire treated in lead baths and salt baths confirmed the practicability of the salt-bath process.

Electric Heat-Treating Facilities are Increased at Bethlehem. (Heat Treating and Forging, 1941, vol. 27, Feb., pp. 85–88, 92). An illustrated description is given of recently completed extensions to the heat-treatment plant of the Bethlehem Steel Co. The principal feature of this plant is the straight-line layout of the hardening and tempering furnaces and quenching tanks. The line extends 330 ft., and the furnaces are designed for 25-ft. bars from $\frac{1}{4}$ in. up to 5 in. in section. Three electrically heated roller-hearth furnaces with a total of seven heating chambers are incorporated in the line, and four car-bottom furnaces have also been installed.

Methods for the Quenching of Steel. Parts I. and II. M. H. Mawhinney. (Industrial Heating, 1940, vol. 7, Oct., pp. 904–909 ; 1941, vol. 8, Feb., pp. 127–130). In the first part of this series of articles on the theory and practice of quenching the author considers how the following factors affect the rate of cooling when steel is quenched in a liquid : (1) The ratio of the surface area to the volume of the part ; (2) the size and shape of the part ; (3) the temperature of the liquid ; (4) the temperature of the steel after quenching ; (5) the thermal conductivity of the steel ; (6) the surface condition of the steel ; (7) the liberation of gases in the bath ; (8) how the part is introduced into the bath ; (9) circulation of the cooling agent. In the second part details are given of some cooling and circulation systems for cooling the oils used for quenching steel.

Heat-Treatment of Forgings. (Engineering, 1941, vol. 151, Apr. 11, pp. 287–288 : Engineer, 1941, vol. 171, Apr. 11, pp. 247–248 : Iron and Coal Trades Review, 1941, vol. 142, Apr. 18, pp. 441–442). An illustrated description is presented of a new gas-fired heat-treatment plant for small forgings. All the equipment is set up in one

line, and it consists of three loading and cooling racks at each end, five furnaces, four oil-quenching tanks and one water-quenching tank. The furnaces are of the incandescent deep recuperative under-fired natural-draft type, with inside dimensions of 10 ft. long by 5 ft. wide by 2 ft. high. An interesting feature of the equipment is an electrically-driven charging machine which travels on rails along the entire length of the plant. This machine is designed to handle the trays carrying one ton of forgings, and with it a load can be withdrawn from a furnace and quenched in 21 sec.

WELDING AND CUTTING

A New Rational Autogenous Method of Welding—Deep Welding. A. R. Gunnert. (Teknisk Tidskrift, 1941, vol. 71, Jan. 25, pp. 29–34). (In Swedish). The author describes an oxy-acetylene welding technique which has recently been developed by a Swedish company. Considerable economy in the consumption of gases and a fast welding speed are among the advantages claimed for the process. This economy is achieved by reducing the amount of the parent metal which is melted while making the joint. The method described applies to butt welds in plates up to 16 mm. thick, which can be welded in one pass, but thicker plates can also be welded with two passes. The plate edges are unchamfered and the flame is kept vertical to the plate. The burner nozzle is slightly smaller than that which would be used for welding the same thickness of steel by the usual left-hand or right-hand technique, and it is kept well down on to the work so that the tip of the white cone in the flame is about half-way down the gap between the plate edges. For this reason the process is called " deep welding." The filler rod is also kept well down in the gap, and it is given a brisk circular or elliptical movement in the molten metal. As the plates are unchamfered, the amount of filler rod added to make the joint is less than for ordinary welds and the quantity of the gases used for a given length of joint is also reduced. Tensile and impact tests on plates welded in this way have shown that the quality of the joint is fully maintained. Several graphs are presented in which the welding speeds and consumptions of gas and filler rod are compared.

On the Degree of Oxidation and the Nature of Slag Formed during Arc and Torch Welding. D. Rosenthal and D. Rozental. (Welding Journal, 1941, vol. 20, Feb., pp. 92-S–94-S). The authors report on an investigation of the influence of the amount of ferric oxide in the coating on a welding rod on the oxidation of the iron in the core, and of the nature of the slag formed during fusion. Four coating materials were prepared containing 92%, 88%, 72% and 68% of ferric oxide respectively, the remaining constituents

consisting of silica and sodium silicate ; all the rods were of Armco iron. Arc welding was done with A.C., and torch welding with a neutral flame. The products were collected on an Armco-iron plate and the slag was examined by chemical analysis, under the microscope and by the X-ray diffraction method. All the slags were found to contain more iron oxide than did the original coating, the increase varying from 40% to 52%, but no relationship could be established between the two values. A check test by analysing the material obtained by fusing the coating mixture alone showed that the composition after fusion was the same within 2% as that before fusion. The microscope revealed that all the slags, except that lowest in iron, had a similar appearance, whether fused by electric arc or by torch. The X-ray examination showed that the phases containing the two oxides SiO_2 and Na_2O in the slag resulting from arc fusion were amorphous, whilst these phases in the slag resulting from torch fusion were crystalline, owing to the slower rate of solidification.

Preheating—Welding—Normalizing by Induction Hysteresis. C. J. Holslag. (Welding Journal, 1941, vol. 20, Feb., pp. 105–107). The author briefly describes the application of induction heating for preheating and stress-relieving welded joints in large pressure vessels, in high-pressure steam pipes and for other work where it is impracticable to move the part into a stress-relieving furnace.

Remarks on Welding as it is Done. J. L. Avis. (Metal Progress, 1941, vol. 39, Feb., pp. 190–194, 226). The author points out that in spite of welding codes, the employment of welders of long experience and the application of stress-relieving heat treatment after welding, faulty welded joints still occur. He describes and illustrates some examples of welds of good external appearance in which faults were found on sections of the joint being examined, and reminds engineers that electric welding as a means of making joints has not yet been brought to a state of perfection.

Welded Stainless Steel Makes Corrosion-Resistant Chemical Plant. (Sheet Metal Industries, 1941, vol. 15, Mar., pp. 392–398). A number of applications in the chemical industry of different types of stainless steel are described. Some particulars of the correct procedure for the oxy-acetylene welding of stainless steel are also given. It is pointed out that there is now available a niobium-treated 18/8 stainless-steel welding electrode which is practically non-sensitive to intergranular corrosion ; the amount of niobium present in this electrode should be five to ten times the amount of carbon in the stainless steel to be welded, the exact ratio depending on the temperature at which the welded component is to be used.

Welding Metallurgy. Volume 2. Part I. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, Feb., pp. 85–90). The lectures on welding metallurgy which were delivered during 1940 under the joint auspices of the Polytechnic Institute of Brooklyn

and the American Welding Society and published serially were designated volume 1. Abstracts of each lecture have appeared in previous issues of the *Journal of the Iron and Steel Institute*. The second volume, now appearing serially, consists of the lectures to be delivered in 1941. In Part I. the fundamental theory of heat is explained and applied to account for the distribution of heat in a weld and the rate of cooling of the whole heat-affected area. The lectures will eventually be published in text-book form.

Improving Ductility of Oxyacetylene Welds by Aging. J. R. Dawson and A. R. Lytle. (Welding Journal, 1941, vol. 20, Feb., pp. 109-S–112-S). The authors describe their examination of the effects of low-temperature heat treatment on the tensile properties of welded joints and weld metal. In most of their tests heat-treatment temperatures of 110° and 300° C. were used—a form of treatment which the authors refer to as " accelerated ageing." Their general conclusions were as follows : (1) Oxy-acetylene welds, when heated for 24–72 hr. at 110° C., or for 1 hr. at 300° C., improve in elongation and reduction of area by 30–50% ; (2) welds in low-alloy steels containing chromium, molybdenum, nickel, copper up to about 0·64%, or manganese up to about 1·36% are also improved in ductility by this treatment ; (3) in the case of oxy-acetylene welds made with rods containing 0·30% of chromium, ageing takes place in 1 hr. or even less at 300° C., but only after a long period at 110° C. ; (4) the improvement in the ductility after treatment at these low temperatures appears to be even greater than that produced by the usual stress-relieving treatment at 650° C. ; and (5) the mechanical properties were affected very little, if at all, by the low-temperature treatment.

The Effect of the Physical State of Steel upon the Tensile Strength of Brazed Joints. F. C. Kelley. (Welding Journal, 1941, vol. 20, Feb., pp. 96-S–102-S). The author gives an account of an investigation of the tensile strength of brazed joints in four different types of steel which had been subjected to various forms of heat treatment. The steels selected were : (*a*) Low-carbon, cold-drawn Bessemer steel ; (*b*) steel with 0·35% of carbon ; (*c*) steel with 0·35% of carbon and 3·5% of nickel ; and (*d*) drill steel containing 1·05% of carbon. The brazed joints were made by placing two samples $\frac{7}{8}$ in. in dia. by $2\frac{1}{4}$ in. long end to end with a disc of copper 0·002 in. thick in between and heating the assembly under hydrogen in a small electric furnace. For comparison purposes, unbrazed specimens were similarly tested. With steel (*a*) the tensile strength, yield point and elastic limit of the brazed specimens were slightly lower than those of the blanks. It was found necessary to decarburise steel (*b*) before brazing in order to obtain results approaching those desired ; in this case also the stress-strain curves of the brazed and heat-treated specimens were very similar to those of the heat-treated blanks. With the heat-treated brazed samples of steel (*b*) the quenching set up stresses which were very great,

and in some cases they broke at the yield point. Steel (d) and steel (c), the latter decarburised before brazing, had poor tensile properties and it appeared that the carbon in the drill steel diffused back to the surface before the copper melted during brazing.

Micro-Fissuring in Multiple-Bead Low-Carbon Steel Welds. J. L. Miller and L. R. Kovac. (Welding Journal, 1941, vol. 20, Feb., pp. 114-S–119-S). The authors studied the factors affecting the formation of a peculiarity observed in some specimens of fractured weld metal. This particular type of defect is sometimes called " fish-eye fracture," and it has the appearance of white conical flakes with minute cracks or pin-holes at the centre. Multiple-bead electric-arc welds were made to join together specimens of 1-in., $1\frac{1}{2}$-in. and 2-in. low-carbon steel plate. It was observed that when the weld was cooled to 0°, 32° or 70° F. after the deposition of each bead the micro-fissures were present, but test plates welded at the same initial temperatures without any intermediate cooling showed a complete absence of these fissures. Heat treatment at temperatures ranging from 800° to 1700° F. had no effect on the size or the number of the fissures present, and it was noted that these fissures occurred only in the fine-grained recrystallised zones. The use of a high-manganese electrode had no effect on the fissure formation. The authors believe that this type of defect is caused by internal stresses arising from the temperature gradient existing between the hot weld metal and the cold parent metal.

MACHINING

The Mechanism of the Wear of Hard Metal Alloys. W. Dawihl. (Stahl und Eisen, 1941, vol. 61, Feb. 27, pp. 210–213). The author reports on some investigations of the wear-resistance of cutting tools made of two types of alloy, namely, tungsten-carbide/cobalt base alloys with and without additions of titanium carbide. He also compares the cutting properties of these alloys with those of high-speed steel. The observations made show that it is not only the mechanical stress on the tool which governs the amount of wear, but also a welding phenomenon by which metal particles of the tool become welded on to the work. It was apparent that tools of the alloy containing titanium carbide had much less tendency to weld than those in which there was no titanium carbide. The latter tools are therefore suitable for machining non-metallic materials such as synthetic resin, carbon, glass, wood and ceramic substances, whilst the former should be used for soft and medium-hard steels which are weldable at low temperatures. The alloy containing titanium carbide is also recommended for machining grey cast iron. It was also found that much higher machining

speeds were possible with both these alloys than with 18/4/1 (tungsten-chromium-vanadium) high-speed steel.

Coolants for Cutting Steel with Carbides. J. R. Longwell. (Iron Age, 1941, vol. 147, Mar. 6, p. 53). The author stresses the importance of providing an adequate supply of a suitable cooling agent for machining at high speeds with cemented carbide tools. He describes and illustrates some piping systems for delivering the cooling agent at the desired spot.

CLEANING AND PICKLING OF METALS

Cleaning Forged Steel. (Heat Treating and Forging, 1941, vol. 27, Feb., pp. 68–69, 76). An illustrated description is given of a new machine for cleaning the inside and outside surfaces of shell forgings. The shells are placed in the machine nose downwards, and the inside is cleaned by metallic grit projected by compressed air from three nozzles. The outside is cleaned by a scraper device requiring no compressed air.

The Effect of the Type of Scale on the Pickling of Iron. J. Sittard. (Metallwirtschaft, 1940, vol. 19, Nov. 1, pp. 971–977; Nov. 8, pp. 1008–1012). The author reports on his investigation of the manner in which different types of scale and other factors affect the pickling of steel sheet. Specimens of two types of copper-bearing steel containing 0·14% and 0·075% of carbon respectively were treated with sulphuric, hydrochloric and nitric acids. The total weight of the scale and the amounts of scale dissolved and split off during different periods of immersion were determined. It was found that the form of scale had a most important effect on the pickling process. With a smooth, dense and uniform scale, the pickling proceeded by solution in the acid with practically no splitting off by the formation of hydrogen underneath the scale. With increasing numbers of cracks and non-uniformity of the scale the amount removed by solution decreased and that removed by splitting off increased. The pickling conditions, such as bath temperature and acid concentration, are not nearly so important as the physical condition of the scale in their effects on acid consumption and loss of metal ; in fact, better pickling is obtained with a uniform scale in a bath without an inhibitor than with a non-uniform scale with an inhibitor. The rate of pickling, on the other hand, is determined by the temperature and acid concentration. It increases with temperature and is at a maximum with that acid concentration which dissolves the scale most rapidly. With sulphuric acid, increasing the concentration increases the rate of scale solution whilst the rate of iron solution remains unchanged. The addition of nitric acid to the pickling bath, or a dip in nitric acid after pickling in a

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different acid, removes the dark grey skin which is left on the steel surface after pickling.

Pickling Stainless Steel. L. F. Loutrel, jun. (Steel, 1941, vol. 108, Jan. 27, pp. 54–55 : Metal Finishing, 1940, vol. 38, Dec., pp. 645–646). The author discusses some of the advantages of a pickling solution for stainless steel consisting of anhydrous ferric sulphate and hydrofluoric acid, and explains why this solution is superior to both hydrochloric and sulphuric acid solutions.

The Testing of Inhibitors for Pickling Solutions. W. Machu and O. Ungersböck. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 263–265). After discussing the difficulties experienced in the usual time-consuming methods of determining the relative merits of different inhibitors for pickling solutions, the authors describe a simple and rapid testing procedure which they have developed. In order to be of practical use for industrial pickling, an inhibitor must be capable of preventing the attack of the acid on the metal even after many charges have been dipped in the bath and when the proportion of inhibitor present is very small. The procedure proposed is based on the fact that the lower the concentration of the inhibitor when testing its efficiency by loss-in-weight determinations, the greater will be the difference in the inhibiting efficiency of good and bad inhibitors. It is therefore necessary to make loss-in-weight determinations at only one, instead of several, inhibitor concentrations, and that concentration should be as low as possible, say about $0.0025–0.005\%$.

The Reclamation of Waste Pickle Liquor. J. H. G. Willan. (Sheet Metal Industries, 1941, vol. 15, Apr., pp. 487–489, 491). The author reviews the processes of reclaiming spent liquors from pickling plants. Some of these are in actual operation and others are proposed as practical and economic methods. The waste liquor may be treated by a number of processes based on one of the three following principles : (1) All of the liquor, which includes the free acid together with the sulphate, is converted into sulphur dioxide gas and then, by suitable treatment, into sulphuric acid ; (2) the ferrous sulphate is separated from the mother liquor and is converted into sulphuric acid by suitable treatment, and the mother liquor, after enrichment with fresh acid, is returned to the pickling tanks ; and (3) the free acid is neutralised by a suitable agent, usually some form of lime, and sometimes the precipitate is processed and made into a saleable product.

COATING OF METALS

Protective Coatings on Metals. P. A. Cartwright. (Journal of the Junior Institution of Engineers, 1941, vol. 51, Feb., pp. 117–135). The author briefly describes the methods of plating steel

and various non-ferrous metals with copper, nickel, zinc, chromium, silver, cadmium, tin, lead, platinum, antimony and cobalt, with particular reference to the composition of the solutions used. He concludes with some brief observations on the characteristics of a number of paints and oils.

Factors in the Production of Perfect Nickel Plating. S. Wernick. (Journal of the Electrodepositors' Technical Society, 1940, vol. 16, pp. 35–44). The author deals at some length with the degreasing of the steel base metal, which is essential for the production of nickel coatings with adequate adhesion, and discusses, in particular, the use of alkali cleansers for this purpose. He then considers how to prevent the formation of blisters, the pitting of nickel coatings, and the causes of nodular or rough deposits.

" Double Boiler " Galvanizing Cuts Maintenance Improves Coatings. A. S. Burnett. (Steel, 1941, vol. 108, Jan. 27, pp. 48–50). The author describes a method of heating galvanising tanks for which many advantages are claimed. For this method a double-walled tank is used, the space between the walls being filled with lead kept molten by electric heaters immersed in it. The advantages of employing this system of heating are : (1) The heat is transmitted to the zinc much more uniformly than by other methods of heating ; (2) the life of immersion heaters in molten lead is much longer than in zinc ; (3) as lead is the heavier metal, the inner lining will be subjected to compressive stresses, with the result that, if the zinc should corrode through the lining, the lead will enter the bath and collect at the bottom, instead of the zinc running out and damaging the brickwork ; (4) with a properly designed tank and with the immersion heaters at proper level, the bottom of the zinc bath is maintained at a lower temperature than the working level ; this ensures longer tank life, less dross formation and a smoother surface on the galvanised parts ; and (5) very precise temperature control can be maintained for small tanks with a single thermocouple in the molten lead, and for larger installations with two thermocouples, one in the lead and one in the zinc.

Galvanizing Characteristics of Different Types of Steel. R. W. Sandelin. (Wire and Wire Products, 1940, vol. 15, Nov., pp. 655–675 ; Dec., pp. 721–749 ; 1941, vol. 16, Jan., pp. 28–35). In this series of articles the author reports on several investigations of the relation between the composition and properties of a steel and the appearance and quality of the zinc coating produced on it by the hot-dip process. In Part I. the influence of the composition of the steel on the appearance and adherence of the coating is dealt with. It was evident from the results of many tests that the presence of phosphorus and/or silicon is the most important factor affecting the appearance of the coating. When they were present in fairly large amounts in the steel, either singly or in combination, the coating had a grey appearance when the dip was of short duration ; with longer immersion periods and with less phosphorus and silicon

present, bright galvanised coatings could be obtained. Increasing the time of immersion of high-phosphorus steels produced a roughening effect on the coating, whilst with high-silicon steels there was practically no roughness. Other conclusions reached by the author were : (1) Variations in the manganese content of the steel have no important effect on the coating ; (2) the presence of copper in the steel has a slight detrimental effect, in that it reduces the adherence to some extent ; and (3) both silicon and phosphorus have a marked effect on coating adherence, as dull coatings always have poor adherence qualities. In Part II. the author considers how the thickness and microstructure of the coating are affected by the composition of the steel. His conclusions on these points were : (1) Neither copper nor manganese has any appreciable effect on the thickness or microstructure of the coating ; (2) as the silicon content of the steel is increased up to 0.10% the thickness of the coating increases ; further increases in silicon up to about 0.20–0.30% lighten the weight of the coating, but with still higher silicon the weight increases rapidly ; (3) in the absence of silicon, increasing the phosphorus content causes a large increase in the weight of the coating without increasing the thickness of the boundary layer ; (4) changes in the carbon content of the steel have no marked effect on the thickness or structure of the coating ; (5) increasing the titanium content increases the thickness and definition of the boundary layer, but decreases the total thickness of the coating, particularly after long immersion ; (6) increasing the aluminium content has the same effect as adding titanium ; and (7) when changes in the composition of the steel increased the thickness of the boundary layer and decreased the total thickness, this was accompanied by a tendency to galvanise bright after long immersion periods. In Part III., which concludes the paper, the results of a large number of wrapping tests to determine the cracking tendency of the galvanised coating on steel wire, are presented and discussed.

American Hot-Dip Tinning Practice. 3. Tinning Gray Iron Castings. W. G. Imhoff. (Metal Finishing, 1940, vol. 38, Dec., pp. 641–644, 646). Continuation of a series of articles (*see* Journ. I. and S.I., 1940, No. II., p. 115 A). The author describes in detail the following operations in the tinning of grey-iron castings : (*a*) Cleaning by sand-blasting, abrasive wheels and tumbling ; (*b*) pickling ; (*c*) washing ; (*d*) fluxing ; (*e*) rough-tinning in the first pot and finish-tinning in the second pot ; (*f*) quenching in paraffin ; (*g*) rinsing in cold water ; and (*h*) drying in sawdust.

Metal Spraying. (Iron Age, 1941, vol. 147, Feb. 6, pp. 46–50). Numerous examples of the successful application of the process of spraying zinc on to steel with the Schori gun are described and illustrated. In this process the zinc is supplied to the gun in powder form, not as a wire. The coating produced is about 0.003 in. thick, equivalent to about $1\frac{1}{2}$ oz. per sq. ft. In addition to the

gun, the necessary equipment includes a zinc powder container, acetylene or propane cylinder, oxygen cylinder, a source of compressed air and the necessary tubing and pressure gauges.

The Granolite Treatment for Piston Rings. (Engineering, 1941, vol. 151, Apr. 11, p. 286). A brief description is given of the Granolite process of treating piston rings, the object of which is to produce a smooth, relatively soft and slightly porous surface which assists the running-in of pistons. in internal-combustion engines. This treatment comprises dipping the finished-machined rings in a hot bath of dilute phosphoric acid saturated with iron and also containing manganese. When a ring is dipped into the bath a slight attack of the iron takes place, but this soon ceases owing to the deposition on the surface of iron-manganese phosphate. After treatment the rings are dipped in oil. The phosphate coating possesses high oil-retaining properties and is softer than cast iron.

Formation of Blisters, Pinholes and Black Specks on Vitreous-Enamelled Cast Iron. A. L. Norbury. (Institute of British Foundrymen and Institute of Vitreous Enamellers, Joint Meeting : Foundry Trade Journal, 1941, vol. 64, Mar. 6, pp. 161–164). The author discusses three possible causes of the evolution of gas from iron castings during enamelling. These are : (1) A reaction between an oxidised inclusion and the carbon in the metal with the formation of carbon monoxide and carbon dioxide ; (2) a reaction between the graphite or a carbide in the metal and an oxide in the enamel with the formation of the same two gases ; and (3) the release of gases which have been trapped in the metal during solidification. When a bubble of gas rises to the surface of the enamel and bursts, it carries with it part of the discoloured enamel from the iron-enamel interface and this causes a dark spot. If gas is still being evolved as the enamel sets, a pinhole will be left in the surface. The author also considers the effects of coarse and fine graphite flakes in the iron on the evolution of the gases.

Service Life of Coal-Tar Enamel Protective Coatings. H. Hayes. (Journal of the American Water Works Association, 1940, vol. 32, Oct., pp. 1705–1722). The author reports on an investigation of the service life of steel pipes with coal-tar coatings which was carried out at the Protective-Coating Laboratory of the Los Angeles Bureau of Water Works and Supply. It was found that coal-tar, when correctly applied, offers permanent protection against corrosion. Even the oldest of the coatings examined, which had been applied 46 years ago to the steel plates of a dry dock at North Shields (England), would have lasted many years longer if kept in service. From the results of water-penetration tests it is to be expected that the newly developed coal-tars, as specified in the American Water Works Association standards, have as long a life submerged in water as the old types. These new coal-tar coatings, however, have the advantage of improved mechanical properties as compared with those of the original coatings, a fact

brought out by the results of abrasion tests which are quoted in the paper.

Steel Dips into New Coatings. H. D. Kolb. (Blast Furnace and Steel Plant, 1940, vol. 28, Nov., pp. 1069–1072). The author reviews the properties of the different types of protective coatings which are now used by steel mills for the temporary protection of steel surfaces against rust during transit and storage. The use of oils containing an inhibitor to prevent the destructive effect of oxygen on the oil molecules is advocated, and reference is made to very light fluids forming a thin film which can scarcely be seen ; the latter is used on sheet and strip and can be applied by a continuous process at a fairly high speed. In conclusion some laboratory accelerated-corrosion tests are described.

PROPERTIES AND TESTS

Supporting Stresses in Crystal Lattices at Right-Angles to a Previously Applied Tensile or Compressive Stress. J. Pirkl. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Nov., pp. 233–246). From the results of experiments on gliding in single crystals the behaviour of grains in an aggregate, with gliding either hindered or promoted by the inclination of the glide-planes in neighbouring grains, has been deduced, and the occurrence of transverse supporting stresses under load in tension or compression derived. From a grain in process of gliding a supporting stress of the same kind spreads perpendicularly to the acting stress. It is independent of the inclination of the plane in process of slip, and depends only on the ratio of the momentary resistance to slip to the shear stress acting on that plane. The magnitude of the variation of the supporting stress with increasing distance from the origin is derived, and the field of stress of the transverse supporting stresses spreading from several places of slip is demonstrated.

The phenomena of elastic and plastic deformation, of flow and yield point, of work-hardening, necking and fracture under tension and compression are explained by the above views on supporting stresses and by the occurrence of active, frozen and arrested gliding. Deviations from the fundamental steady glide are unsteady and arrested flow, in which structural constituents such as plates of cementite in steel, or grain boundaries, behave as obstacles. The effects of the displacement of grains from the direction of the applied load, especially at the surface of a bar under compression, are described, and the cause of rupture by shear is demonstrated.

Seeing Stresses with Photo-Elasticity. W: M. Murray. (Metal Progress, 1941, vol. 39, Feb., pp. 195–200). The author describes the optical method of stress analysis by the examination of models

with polarised light and explains how, in the case of a loaded beam, the data obtained can be used to calculate the " stress concentration factor," which is defined as the maximum true stress divided by the maximum apparent stress as determined by the simple beam formula. The maximum true stress in any geometrically similar beam can thus be computed by multiplying the maximum apparent stress for that beam by the stress concentration factor. Although photo-elastic analysis is primarily two-dimensional in character, a recent development has enabled the technique to be adapted to many three-dimensional problems. This development makes use of a property of bakelite which permits the stress pattern in the model to be " frozen." An example is given using a bakelite model of a safety-valve disc. The model is loaded, heated to a temperature slightly above the boiling point of water, and then cooled slowly with the load still on it. At the elevated temperature a considerable deflection takes place which can be retained by cooling under load. Upon removal of the load very little recovery of deformation takes place, and, more important still, the photo-elastic stress pattern is retained. The model can then be cut up into slices and the stresses in each slice determined, thus enabling a complete picture of the position of high and low stresses throughout a solid body to be obtained.

Stresses in Rotating Parts. M. Hetenyi. (Metal Progress, 1941, vol. 39, Feb., pp. 200–201). The author describes a particular application of the " freezing " method of obtaining photo-elastic stress-concentration diagrams in bakelite bodies (*see* preceding abstract). In this example a disc containing one shaft hole in the centre and two series of concentric bolt holes was rotated at a constant speed while it was being annealed. The distribution of the centrifugal force was thus revealed.

Improving Engine Axles and Piston Rods. O. J. Horger and T. V. Buckwalter. (Metal Progress, 1941, vol. 39, Feb., pp. 202–206). The authors describe how the combined study of rotating-bending fatigue test data and of photo-elastic stress diagrams led to an improvement in the design of locomotive axles and piston rods. In the case of the former an increase of 80% in the fatigue strength of the axle at the wheel seat was obtained with an increase of only 4% in the weight of the material.

The Torsional Fatigue Strength of Shafts of Carbon and Alloy Steel. F. Bollenrath and H. Cornelius. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 283–287). The authors report on an investigation of the torsional fatigue strength of solid and hollow specimens 12, 30 and 60 mm. in dia. prepared from a 0·6% carbon steel, a low-alloy steel containing 1·50–1·65% of chromium and 4·2% of nickel, and a low-alloy steel containing 2·46% of chromium and 1·50–1·56% of nickel. The effects of size, tensile strength and structure were determined. With small specimens the alloy steels had much better fatigue properties than the tem-

pered carbon steel, but the heavy specimens of tempered carbon steel had fatigue properties equal to those of the alloy steels. .

The Notch-Sensitivity Coefficient of Cold-Worked Steels when Subjected to Bending Fatigue. H. Cornelius and F. Bollenrath. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 289– 292). The authors report on fatigue tests made with plain and with notched specimens to determine the effect of previous cold-work on the notch-sensitivity of the steel. They found that as the degree of cold-work was increased the notch sensitivity of soft iron, of chromium-molybdenum heat-treatable steel and of a carburised austenitic steel also increased. The notch-sensitivity of 0·38% carbon steel decreased slightly with increasing amounts of previous cold-work. This reduction was observed to be more marked with a chromium-nickel-molybdenum heat-treatable steel. In the soft state the carburised austenitic steel had no notch sensitivity, and when cold-worked only a slight notch-sensitivity.

The Modulus of Elasticity and Damping Capacity of Iron and Iron Alloys. W. Köster. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 271–278). The author describes Förster's acoustic method of determining the elastic modulus and damping capacity of steel specimens (*see* Journ. I. and S.I., 1937, No. I., p. 44 A). This method is based on the measurement of the pitch and duration of the sound emitted by the specimen when vibrated under certain conditions. The addition of alloying elements has little effect on the elastic modulus, but the graphite in cast iron has a pronounced effect on this property and on its damping capacity. Tests up to 1000° C. showed that the magnetic transformation which takes place at 768° C. accelerates the increase in the elastic modulus of pure iron. At room temperature, on the other hand, the temperature coefficient of the elastic modulus of ferromagnetic α-iron is less than that of paramagnetic α-iron above the Curie point. The α ⟶ γ transformation of iron causes an increase in the elastic modulus. The elastic moduli of paramagnetic α-iron and of γ-iron bear a linear relationship to the temperature. The damping capacity increases markedly as the temperature rises above 600° C., and an increased damping capacity is also noted at about 100° C. The relation between the elastic modulus and the temperature of iron alloyed with 4% of silicon is similar to that for pure iron. It is apparent from the temperature/elastic-modulus curve of an unalloyed steel that the value of the latter falls in a temperature region corresponding to the presence of ferromagnetic cementite. The elastic modulus of iron is not dependent on the grain size, but it is lowered a little and the damping capacity is greatly increased by stretching the specimen ; this increase in damping capacity is still greater with iron-carbon alloys. Whilst ageing iron at room temperature increases the elastic modulus slightly, the damping capacity soon returns nearly to its original value. Unalloyed steel behaves in the same way when aged but the change takes place

more slowly. The heat treatment for hardening commercial iron does not affect the elastic modulus. The elastic properties of an iron-cobalt-chromium alloy and their dependence on temperature are presented. In conclusion the author points out that the measurement of the damping capacity is a good method of detecting faults in steel and is also a suitable technique for the study of intercrystalline corrosion.

Jominy Test of Meehanite Metal. A. C. Denison. (Foundry Trade Journal, 1941, vol. 64, Mar. 27, pp. 207–209). The author describes a form of Jominy end-quench hardenability test in which a heated specimen of iron or steel 1 in. in dia. $\times$ $2\frac{3}{4}$ in. long is held vertically and quenched by bringing it down until an upward-directed jet of water impinges on its lower end ; a series of Brinell tests is then made along the bar at progressive distances from the quenched end. He also presents several series of curves which demonstrate the influence of the temperature from which specimens of Meehanite were quenched, the soaking time at that temperature, and the composition on the hardenability of that metal. Tests made at quenching temperatures of 828°, 860° and 885° C. and with soaking periods varying from 3 min. to 1 hr. showed that changes within these limits had little effect on the hardenability, except when the manganese content was high, in which case soaking for at least 30 min. at 860° C. proved to be a suitable treatment. Changes of silicon content within the range 1·14–1·68% had little effect on the hardenability. Increasing the manganese content had a marked effect in retarding the reaction rate and increasing the hardenability, and the optimum manganese content was about 1·50% for practical purposes. In reviewing the test results the author favours manganese rather than chromium as a hardening alloy, but considers that there is room for more investigation on the effect of chromium, especially for heavy-section work where moderate percentages do not harm the pearlitic structure of Meehanite.

Cast-Iron Cylinder Bores—Observations on Microstructure, Composition, Hardness and Wear. E. K. Smith. (Transactions of the American Foundrymen's Association, 1941, vol. 48, June, pp. 667–709). The author studied the structure, analysis and hardness of cast-iron automobile cylinder blocks in new condition and after various periods of wear. He found that there appears to be a relationship between the amount of ferrite present and the wear. The more ferrite the greater was the wear, provided that normal thin flakes of graphite were present. He comments on some special cases involving such defects as porosity and excessive wear, and reviews the literature on the causes and prevention of the wear of cylinder bores. In his opinion the best structure at the position of maximum wear consists of an entirely pearlitic matrix with thin flakes of normal graphite and some particles of iron-chromium carbide.

Spark Test as a Plant Control. H. A. Maloney. (Metal Progress, 1941, vol. 39, Feb., pp. 209–211). A brief account is given of how the spark test for checking the sorting of steel according to analysis is carried out at the works of an American automobile manufacturer.

The Measurement of Magnetostriction in Transformer Alloys. W. Alexander. (Beama Journal, 1941, vol. 48, Feb., pp. 20–22; Mar., pp. 37–39). The author reports on his investigation of the measurement of magnetostriction in transformer alloys and of the influence of the magnetostriction on the noise emitted by transformers. He applied a mechanical-optical method of measurement, using a system known as Lamb's extensometer. The instrument, which is described in detail, had an extremely smooth action, and this made it possible to obtain satisfactory hysteresis curves at very small values of magnetising force. The data obtained formed a basis for the development of the theory of the transformer as a source or emitter of sound. A general consideration of the information shows that the noise from a transformer will not be directly proportional to the intensity of magnetisation, because the relationship that holds between the magnitude of the magnetostrictive effect and the flux density is not linear.

A Determination of the Magnetic Saturation Induction of Iron at Room Temperature. R. L. Sanford and E. G. Bennett. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, No. 1, pp. 1–12). The authors describe an investigation of the magnetic saturation induction of some iron ingots of exceptional purity, using a modification of the isthmus method of Ewing and Low. Corrections were made for the effect of the small amounts of impurities present. The value found for pure iron at 25° C., assuming its density to be 7·874 g. per cu. cm., was $21·58 \pm 0·01$ kilogauss.

Fundamentals of High Temperature Testing of Steel. J. Glen. (Journal of the West of Scotland Iron and Steel Institute, 1940–41, vol. 48, Part II., pp. 19–34). The author describes and explains the mechanism of the strain-hardening and strain-ageing of steel, with particular reference to the effects of time and temperature. He shows that at temperatures of about 500° C. and above, the effect of time at the service temperatures becomes of increasing importance and may cause a serious decrease in the strength of the steel. He discusses how the following factors influence the results of tensile creep tests : (a) The technique of testing ; (b) the chemical composition ; (c) the process by which the steel was manufactured ; (d) the grain size and heat treatment ; (e) the temperature ; (f) the amount of cold-work ; and (g) intercrystalline cracking. In conclusion some American, German and English methods of determining the creep properties of steel and of presenting and interpreting the results are described.

How Grain Size Affects Creep Strength. S. H. Weaver. (Steel, 1941, vol. 108, Feb. 24, pp. 80–85, 92). The author describes his

investigation of the manner in which the grain size affects the creep properties of some low-alloy steels. Steels from four heats of 0·20% carbon steel alloyed with small quantities of chromium, nickel, tungsten and molybdenum in various combinations and heat-treated to produce different grain sizes were used in the creep tests. In this paper the author expresses creep strength in pounds per square inch required to produce 1% elongation in 100,000 hr. It was apparent from long-time creep tests at 1022° and 1112° F. that all four types of steel had better creep properties in the annealed than in the normalised and in the tempered state, and that each of the four types had a different optimum grain size for the highest creep strength. An analysis of the results of many creep tests showed that : (a) At the lowest temperature of testing the steel with the finest grain had the greatest creep strength ; (b) at the highest temperature the steel with the coarsest grain had the greatest creep strength ; and (c) at intermediate temperatures the greatest creep strength was exhibited by the steel with an intermediate grain size. In conclusion, the author explains a method of predicting the approximate creep strength of a molybdenum steel from its chemical composition and microstructure which involves the application of curves obtained by plotting the creep strength against temperature for various A.S.T.M. grain sizes of a 0·5% molybdenum steel.

A Study of Some of the Factors Affecting the Resistance of Cast Iron to Deflection under Load at High Temperatures. L. W. Bolton. (Iron and Steel Institute, 1941, this Journal, Section I.). A study was made of some of the factors affecting the resistance of cast iron to deflection at high temperatures. A method of testing was developed in which a bar of standard dimensions was rigidly held at one end, while the other end was loaded, the stressed portion of the bar being held at a constant temperature of 850° C. The deflection of the free end of the bar was recorded and measured.

The effect of composition was studied and it was found that both silicon and phosphorus increased the resistance of cast irons to deflection at 850° C. Graphite size was found to have an important influence on the results obtained, and in the case of irons of similar composition, those having coarse graphite flakes will deflect more rapidly than those in which the graphite is in a finer state of division.

Three plain carbon steels were tested for comparison, and it was found that the rigidity of these steels at 850° C. was less than that of many of the cast irons tested.

An examination was also made of the rigidity of two types of austenitic cast iron. These were found to have a good resistance to deflection at the temperature of the tests. The rigidity of these austenitic irons was increased by additions of chromium.

Effect of Low Temperatures on the Properties of Aircraft Metals. S. J. Rosenberg. (Journal of Research of the National Bureau of

Standards, 1940, vol. 25, Dec., pp. 673–699). The author reports on an investigation of the tensile, hardness and impact properties, at temperatures down to − 78° C., of metals commonly used in aircraft construction. The materials tested were divided into three general groups : ferritic steels, austenitic stainless steels and nickel alloys, and aluminium- and magnesium-base alloys. The results of tests are given in numerous tables and graphs. In general, the tensile strength and hardness of all the materials increased with decreasing temperature. The resistance to impact of the ferritic steels decreased generally as the test temperature was lowered, the rate and nature of the decrease depending on the type of steel and its treatment. The impact resistance of the austenitic stainless steels and the nickel alloys was not deleteriously affected, and they were considered the most suitable for service at low temperatures.

Molybdenum Cast Steels. (Foundry Trade Journal, 1941, vol. 64, Mar. 27, p. 214). A brief summary is presented of the potential advantages to be derived from molybdenum additions in the production of steel castings, and some tables of properties of carbon-molybdenum cast steels are given.

The Influence of the Accompanying Elements on the Changes in the Strength Properties of Normalised Soft Steel in the Blue-Brittle Region. W. Eilender, H. Cornelius and P. Menzen. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Nov., pp. 217–221). The authors examined the influence of nitrogen, oxygen, sulphur, phosphorus and manganese on the mechanical properties of a number of steels with carbon in the range 0·006–0·15% in the normalised state and in the blue-brittle range. Tensile tests were made at temperatures of 20° to 350° C., and the data obtained showed that the increase in the tensile strength and the decrease in the elongation and reduction of area were caused by the nitrogen present and that the sulphur, phosphorus and manganese had no effect under the conditions described. The oxygen may have had some effect, but this was very slight. The effects of carbon and silicon were not altogether clear, but the carbon appeared to counteract the nitrogen to a slight extent. It is pointed out that these results apply only to normalised soft steels.

A Hard Basic-Bessemer Structural Steel Killed with Silicon and Aluminium. H. Hauttmann. (Stahl und Eisen, 1941, vol. 61, Feb. 6, pp. 129–136 ; Feb. 13, pp. 164–168). The author discusses the introduction in Germany in 1924 of structural steel St48 and the reasons for discontinuing its use in 1929. Later on the need for a reliable structural steel with properties between those of St37 and St52 became more and more apparent, so that in 1937 Gutehoffnungshütte Oberhausen A.-G. carried out an extensive investigation of a suitable method of manufacturing a steel with a tensile strength of 48 kg. per sq. mm., an account of which forms the subject of the present paper. The basic Bessemer process, as that most suited to the German ores, was applied with the follow-

ing objects in view : (1) Limitation of the carbon content of the finished steel to 0·25% max. ; (2) alloying with up to 0·4% of silicon to kill the steel and to raise the elastic limit and tensile strength ; (3) the raising of the manganese content to 0·6–1·0% ; and (4) the addition of sufficient aluminium to leave a few hundredths of 1% as metal in the finished steel. Full details are given of the results of tensile, impact, fatigue, cold-working and weldability tests. These proved that a satisfactory steel with the required properties can be produced by the method described.

A Planned Marking System for Steel Standards. F. P. Fischer. (Stahl und Eisen, 1941, vol. 61, Mar. 6, pp. 238–242). After reviewing the systems of marking steel according to composition and properties which have been adopted in the United States and in Switzerland, the author proposes a system which is in part based on the work of Committee 17 of the International Federation of the National Standardizing Associations. This system covers carbon and alloyed structural steels, the latter containing up to 5% of the alloying element.

METALLOGRAPHY AND CONSTITUTION

The Electron Microscope. A. L. G. Rees. (Chemistry and Industry, 1941, vol. 60, May 3, pp. 335–337). The author reviews the development and present limitations of the following types of microscope : (a) The scanning electron microscope ; (b) the shadow electron microscope ; (c) the electrostatic electron microscope ; and (d) the magnetic electron microscope. He compares their limits of resolution, and points out that the application of ultramicroscopic methods, where the object is illuminated by dark ground illumination, will enable objects far beyond the resolving power of the instrument to be observed.

A Rapid Electrolytic Process for the Polishing of Metal Sections. A. L. De Sy and H. Haemers. (Stahl und Eisen, 1941, vol. 61, Feb. 20, pp. 185–187). The authors describe a modification of Jacquet's electrolytic process for the polishing of metallographic specimens of steel and aluminium. In the modified process the electrolyte consists of a mixture of 1 volume of $HClO_4$ (sp. gr. 1·12) and 4 volumes of C_2H_5OH treated with 3% of ether ; the bath temperature must not exceed 35° C. and the current density must be at least 2 amp. per sq. cm. Current must be available at at least 110 V. for small specimens, whilst 150–220 V. is required for specimens 15–20 mm. in dia. With this process the total time required to polish steel specimens is only 1–2 min., and for aluminium specimens about 3 min. are required.

Rate of Diffusion of Manganese in Gamma Iron, in Low-Carbon and High-Carbon Manganese Steels. C. Wells and R. F. Mehl.

(American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1282; Metals Technology, 1941, vol. 8, Feb.). The authors determined the rate of diffusion of manganese in γ-iron and in low-carbon and high-carbon steels over temperature ranges of 1050° to 1450° C. and 1000° to 1250° C., respectively, and at compositions between 4% and 60% of manganese and between 0·02% and 1·25% of carbon. The values obtained were accurate with $\pm$ 15%. They found that the rate of diffusion of manganese increases by about 125% as the composition changes from close to zero to 60% of manganese, and by about 350% as the carbon is increased from zero to 1·5%. This percentage change in the rate of diffusion with increasing manganese or carbon content is practically independent of the temperature. Impurities normally present in commercial steels did not affect the results appreciably; even silicon contents of 0·3% to 1·0% had hardly any effect. Also the grain size of the specimens did not seem greatly to affect the rate of diffusion of manganese in γ-iron. The authors calculated the activation heat of diffusion at various manganese concentrations and developed diffusion equations at manganese concentrations of 4% and 14% and at carbon concentrations of 0·02% and 1·25%. They also provide two empirical equations by which the values of the diffusion rate of manganese can be calculated up to 20% of manganese and up to 1·5% of carbon, respectively.

Structural Analysis of Gray Cast Iron. D. J. Reese and R. A. Flinn. (Foundry, 1941, vol. 69, Jan., pp. 38–40, 106–108). It is sometimes found that grey cast irons of the same chemical composition cast under identical conditions have quite different properties. In the present paper the authors describe how the correlation of information revealed by the microscope and by X-ray diffraction technique provides an explanation of these differences.

The Solidification and Graphitization of Gray Iron. C. D. D'Amico and R. Schneidewind. (Transactions of the American Foundrymen's Association, 1941, vol. 48, June, pp. 775–803). The authors describe an investigation which they conducted to test the theory that the graphite pattern in any given iron is determined by the following factors: (1) The rate of cooling of the iron during solidification; (2) the degree of undercooling; and (3) the solidification characteristics of the iron, i.e., whether it solidifies in the white, mottled or grey state. They studied the graphite formation in five irons of widely different compositions by means of undercooling tests similar to those described in an earlier paper (see Journ. I. and S.I., 1939, No. II., p. 174 A). The above theory was found to be correct and it was shown that factor (3) could be controlled by deoxidation. The influence of undercooling on the process of solidification and graphitisation of cast iron can be represented by a cooling curve similar to the S-curve for the austenite transformation. Each part of the curve represents a particular type of graphite formation. The upper part represents a random distribution of flake graphite.

The middle part of the curve represents a eutectiform dendritic graphite and the lower part the mottled and white irons.

A New Diagram for the Structure of Cast Iron. K. Sipp. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 267–269). The author discusses methods of constructing diagrams for predicting the structure of cast iron when the carbon and silicon contents and the cooling rate are known. He constructs a new type of diagram in which he uses Heyn's figures for the degree of carbon saturation as abscissæ, and the thicknesses of the test specimens as ordinates. The results obtained with specimens 10–100 mm. in dia. are compared with those predicted by the diagram, and a general relationship between the degree of carbon saturation and the type of structure was found.

The Great Nordenskiöld Block of Iron from Ovifak—Its Micrography and Metallurgy. H. Löfquist and C. Benedicks. (Jernkontorets Annaler, 1940, vol. 124, No. 12, pp. 633–680). (In Swedish). In 1870 the Swedish explorer Nordenskiöld discovered three huge blocks of ironstone at Ovifak near Fortune Bay in Greenland. The largest of these, weighing about 25 tons, was moved to the Riksmuseum, Stockholm. In 1938 a core was bored out of this block and samples from this were submitted to a complete micrographic and metallurgical investigation. In the present paper the authors report on this work and discuss the results obtained. The block contains an average of 91·8% of iron, 1·8% of nickel and 1·1% of sulphur. It was formerly thought to be of meteoric origin, but from the results of the present work the authors deduce that it is really of terrestrial origin.

The Iron/Iron-Titanide/Chromium-Titanide/Chromium Constitutional Diagram. R. Vogel and B. Wenderott. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 279–282). By means of thermal, X-ray and microscopical investigations the authors constructed the constitutional diagram for the iron-chromium-titanium system up to the pseudo-binary section represented by Fe_2Ti–Cr_2Ti_3. Within this range the products of primary crystallisation are : (1) Ternary solid solutions of α-iron with chromium and titanium ; (2) ternary solid solutions of iron titanide, Fe_2Ti, with α-iron and chromium ; and (3) chromium titanide, Cr_2Ti_3.

BOOK NOTICES

Van Someren, E. H. S. "*Spectrochemical Abstracts.*" Vol. II., 1938–1939. 8vo. pp. 38. London, 1941 : Adam Hilger, Ltd.

This is a continuation of Spectrochemical Abstracts, the first volume of which covered the period 1933–1937. In the present work the arrangement of the first volume has been followed with minor

variations, and the abstracts are numbered consecutively with those of the first volume. A few important earlier papers have been included, and also books published in 1940. Part I. consists of an author index, which gives the full reference to each article. Part II. contains the abstracts arranged in alphabetical order of the subject dealt with.

VOGEL, A. I. " *A Text-Book of Qualitative Chemical Analysis.*" (Second edition.) 8vo. pp. xi + 486. London, 1941 : Longmans, Green & Co. (Price 10*s.* 6*d.*)

This excellent volume is the second edition of the work published originally in 1937, and it contains a number of important additions to the text, as well as the fruits of a thorough revision in the light of practical experience. The reviewer is of the opinion that qualitative analysis should be the keystone in the edifice of the inorganic chemist's training. In the systematic separation of the elements and ions we have combined object lessons on the principles of most of our quantitative analysis, on the workings of the laws of physical chemistry, and on the gradations of properties that are predicted by the Periodic Table of the elements.

The work under review fulfils all these accessory requirements, while dealing most effectively and thoroughly with its nominal subject. The first chapter of nearly one hundred pages is devoted to a discussion of the theoretical basis of qualitative analysis, and covers such items as the ionic theory of solutions, solubility product, electrode potential, hydrogen-ion concentration, and hydrolysis. The second chapter deals with analytical operations, and gives model instructions for the conduct of all the usual laboratory processes. A modified technique is given in some detail for the operations involved in micro- and semi-microanalysis; this section will no doubt be of great interest to those who have neither the time nor the necessity to master the refined and elegant technique developed by the specialist workers in this field. The third and fourth chapters describe the characteristic reactions of the metal ions and acid radicals respectively, and follow well-established lines, but are notable for the detail in which confirmatory tests are given and the frequent recourse to the use of the lesser-known organic and complex inorganic reagents. A good feature is an indication of the sensitivity of these special reagents, both for quantity and for concentration.

The fifth chapter summarises the detailed information already provided and gives the tables for the systematic examination of an inorganic salt or mixture, and the next chapter covers the methods to be adopted when interfering acid radicals are present. The final chapter gives the reactions of some of the rarer elements, and after a description of their individual characteristics, shows how they may be dealt with and identified when their presence is suspected in the course of the normal systematic examination. An appendix contains useful information such as atomic weights, tables of solubilities, and particulars concerning the preparation of reagents and test solutions. It is of interest and value to note that all the reagents mentioned in the book can be obtained from named British and American sources.

This text-book can be highly recommended to all students of chemistry, and the assimilation of its contents will be of great assistance in solving difficulties far beyond the scope of mere qualitative analysis.

STEPHEN L. ROBERTON.

MINERAL RESOURCES

Geology of the Country Around Wakefield. W. Edwards, D. A. Wray and G. H. Mitchell. (Memoirs of the Geological Survey of Great Britain, Explanation of Sheet 78, London, 1940). In this publication a complete account of the geology of the Wakefield district is given, with particular reference to the coal measures.

Mineral Resources of Continental Europe. W. J. Arkell. (Nature, 1941, vol. 147, Apr. 5, pp. 404–407 ; Apr. 12, pp. 443–446). The author presents a synopsis of the resources of the minerals of strategic importance in Europe, but excluding the British Isles, Spitsbergen, Turkey and Russia.

Iron-Ore Resources of Soviet Russia. (Iron and Coal Trades Review, 1941, vol. 142, Apr. 11, pp. 415–416). A survey of the iron-ore resources of the U.S.S.R. is presented. From this it is evident that the Soviet Union possesses immense iron-ore resources fully sufficient to maintain for many years an iron and steel output considerably greater than the present production.

Investigation of the Magnetic Anomalies Relating to the Geological Structures of the Chin-lin-chên Iron-Ore Field, North China. H. Higasinaka. (Journal of the Shanghai Science Institute, 1940, vol. 2, Nov., pp. 7–38). The author reports on a magnetic-geophysical survey carried out in 1937 of the Chin-lin-chên iron-ore beds in Shantung Province, North China.

ORES—MINING AND TREATMENT

Breaking Ore Underground by Means of Long Blasting Holes. Å. Lidén. (Teknisk Tidskrift, 1941, vol. 71, Mar. 8, Bergsvetenskap pp. 17–24). (In Swedish). A detailed description with numerous diagrams is given of the recently developed technique of underground blasting with bore-holes up to 40 m. in length. This technique offers the advantage that a large bed of ore can be broken down at a low cost, because a widely extended area can be reached from one position of the drilling machine.

Modern Concentration Technique and Its Significance in Relation to the Supply of Raw Materials for the Indigenous Chemical and Metallurgical Industries. F. Mogensen. (Teknisk Tidskrift, 1941, vol. 71, Jan. 11, Bergsvetenskap pp. 1–8). (In Swedish). The author reviews recent developments in Sweden and abroad of methods of concentrating minerals, with particular reference to the requirements of the Swedish chemical and metallurgical industries.

Modern Practice in Rotary Kiln Sintering. S. G. Thyrre. (Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1941, vol. 29, Mar., pp. 324–329, 355, 361). The author describes the development of the modern rotary kiln for making iron-ore sinter. The disadvantages of the plain kiln as used in the cement industry are pointed out, and some details and an illustration are given of the boring machine for the removal of the ring of sinter which cakes on to the lining near the discharge end of the kiln. The boring apparatus is used once or twice during each 8-hr. shift, but the frequency depends on the stickiness of the material. It takes 10–15 min. for the bar to pass through the sintering zone and about half that time to withdraw it. Some particulars are also given of the operation of rotary sintering kilns in Luxemburg, South Wales, Cuba and the United States.

Reduction Equilibria and the Magnetising Roasting of Iron Ore. J. Klärding. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Nov., pp. 203–205). The author reports on an investigation of the relation between the magnetic sensitivity and the reducibility of iron oxide and of Fortuna ore. He found that the magnetic sensitivity of the ore was lowered by the chemical reactions between the iron oxides and the gangue, and to prevent these reactions from taking place he suggests that the preliminary reduction in the magnetising roasting should be done with a volatile fuel at a low temperature.

The Deposition of Sludge in Settling Ponds. G. G. Bring. (Jernkontorets Annaler, 1941, vol. 125, No. 1, pp. 1–55). (In Swedish). The author describes an investigation of the settling characteristics of the sludges coming from the ore concentration plants at two Swedish iron-ore mines.

REFRACTORY MATERIALS

Refractories—Some Notes on Their Constitution and Reactions. J. F. Hyslop. (Journal of the West of Scotland Iron and Steel Institute, 1940–41, vol. 48, Part III., pp. 39–42). The author discusses the characteristics of some of the oxides which are the chief components of igneous rocks, slags and refractories, dividing them into the following groups in order of increasing basicity : (a) SiO_2 ; (b) Cr_2O_3, Al_2O_3 and Fe_2O_3 ; (c) MgO, FeO and MnO ; (d) CaO, SrO and BaO ; and (e) Na_2O and K_2O. He points out that the acid oxides have metal ions of high valency and low volume, whilst the basic oxides have ions of low valency and large volume. He gives examples illustrating the fact that the farther the oxides are apart in the basicity series, the more chance there is of the

formation of a new mineral with distinctive characteristics. In conclusion he discusses the reactions between iron slags and chrome-magnesite and straight magnesite refractories.

Firebricks in the Steel Industry. A. E. Dodd. (Refractories Journal, 1941, vol. 17, Mar., pp. 99–103). The author discusses briefly the application of firebricks for gas producers and flues, checkerwork in the regenerator system and other parts of the open-hearth furnace, the ladle, regenerators and covers of soaking-pits, and reheating furnaces.

Furnace Insulation. (Gas Journal, 1941, vol. 234, May 14, pp. 268–270). The properties of the three following types of refractory insulating material for reducing the heat loss from the outside of furnace walls are discussed : (1) Blankets or sectional coverings of asbestos, slag wool and glass silk for use where the temperature of the outside of the brickwork does not exceed 450° C. ; (2) plastic coverings with a magnesium carbonate or oxide base for use on surfaces up to about 300° C., and diatomaceous plastic materials for temperatures up to 800° C. ; and (3) brick-work or powder of a diatomaceous nature which can also be used at up to 800–850° C.

FUEL

The Nature of Flame. K. Rummel. (Stahl und Eisen, 1941, vol. 61, Apr. 10, pp. 364–371). The author presents a summary of the results of several years laboratory investigations of the radiation from burning gaseous fuels. The observations made led to the development of the following theory : The emission of light which accompanies the powerful heat radiation from flames cannot be considered as resulting solely from the splitting up of the hydro-carbons in the fuel into carbon and hydrogen, because many other complicated reactions take place. It may be said that these reactions cause very large solid hydrocarbon molecules high in carbon and low in hydrogen to form themselves into a kind of carbon framework which becomes the emitter of bright light. A " self-carburising " flame is formed by burning gases containing methane (*e.g.*, coke-oven gas) in which, at suitable temperatures, the methane is converted into heavy hydrocarbons and forms this framework ; the temperature range within which this phenomenon occurs is, however, a very narrow one ; below it the methane remains stable, above it it is dissociated. The process of flame formation is affected to an important extent by the manner of mixing and the temperature.

The Flow of Gases in Natural-Draught Furnaces. E. J. Gooding and M. W. Thring. (Journal of the Society of Glass Technology,

1941, vol. 25, Feb., pp. 21–78). The authors report on a study of the flow of gases through natural-draught regenerative furnaces. Their tests were carried out on a glass-tank-furnace system which is very similar to the open-hearth furnace system. From the cold-furnace experiments it was seen that, to a large extent in the air regenerator, and to a slightly smaller extent in the gas regenerator, the incoming air tends to be carried along the channel under the checkerwork before rising. The result of this is that most of the vertical flow occurs at the end farthest from the inlet. The hot-furnace experiments, however, suggest that as soon as the air and gas enter their respective regenerators they rise into the checkerwork, so that the flow tends to be greater at the inlet end. Both in the hot- and cold-furnace experiments the effect of the space above the checkerwork and the resistance of the ports is to even out the flow. It is seen that the flow through the ports is governed by the resistance of the ports and the buoyancy effects in the regenerator and ports. It was therefore possible to alter the flow by changing either the temperature or the resistance. The prevailing temperatures of parts of the system can be changed either by insulation, or by altering the heat capacity, and the resistance of the ports can be altered by suitable structural modifications.

Coal Preparation and Washer Waste Treatment. J. Stafford. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 145, No. 2, pp. 86–88). The author reviews the development of coal-cleaning processes and the treatment of slurries from coal washeries. The latest contribution to the sorting of coal is an electrically operated apparatus, in which the selection depends on the relative resistance of coals and shales to the passage through them of minute electric currents; this apparatus is still in the development stage. The author also gives particulars of a dry method of removing dust from coal, as a result of which the waste water from the subsequent washing process is comparatively clean. In this dry method the raw coal, from 3 in. down to zero, is made to cascade over a series of open louvres through which a controlled draught of air is blown; the dust-free coal falls into a wash-box, whilst the air carries away the fine dust particles. The aspirated dust, 55% of which is smaller than 0·5 mm., is trapped in a cyclone hopper, and the air, now more or less clean, passes on, returning to the fan in an enclosed circuit to be blown through the louvres again. There is no air-vent, and therefore no dust nuisance with this system. The power required at the fan is only 15 h.p. when dealing with an input to the washer of 200 tons of raw coal, and extracting 4 tons of dust per hr.; the efficiency of extraction is about 90%.

Beehive and Byproduct Coking in Washington. J. Daniels. (United States Bureau of Mines, 1941, Mar., Report of Investigations No. 3551). The author presents a report on the coking-coal resources and the coke-oven and by-product practice in the State

of Washington. The information includes material collected since 1915, with the object of determining the feasibility of establishing an iron and steel industry near the Pacific coast.

The Shrinkage of Coke during Carbonisation. G. E. Foxwell. (Coke and Smokeless-Fuel Age, 1941, vol. 3, Apr., pp. 76–80). The author refers to investigations on the shrinkage of coke by the United States Bureau of Mines, from which the conclusion was drawn that cokes from all coals shrink to about the same extent and that the differences in expansion noted probably should be attributed to varying expansion in the plastic layer (*see* Journ. I. and S.I., 1941, No. I., p. 145 A). Other investigators, notably Mott and Spooner, have disagreed with this conclusion. In the present paper the author discusses in detail the methods of investigation employed by the Bureau of Mines, the deductions made and the criticisms of Mott and Spooner, and gives his reasons for supporting the conclusions of the former.

PRODUCTION OF IRON

Cleaning Checkers by the Hydrastatic Method. K. Steinbacher. (Blast Furnace and Steel Plant, 1941, vol. 29, Mar., pp. 303–306). The author points out the difficulty of removing the dust deposited in the checkerwork of blast-furnace stoves, more especially with the modern multi-holed checker system, and describes a water-jet system of cleaning that has been used successfully in the United States since 1934. With this method the stove is isolated from the gas system and allowed to cool sufficiently for men to work in it. A water-supply line is passed through a manhole in the stove top and a manifold with four flexible tubes with special jets is connected to it in the space above the checkers; these jets are passed down the vertical passages in turn. A 6-in. hole is made through the shell-plate at the bottom for draining off the water and sludge. It has been found that if the checkerwork is partially cooled before cleaning and thoroughly dried afterwards, the refractories are not adversely affected nor is the life of the stove shortened. The time required for complete flushing is about 18–20 hr. for three men.

The Fundamentals of the Supply of Power and Materials for Iron-Smelting Processes. H. Bansen. (Stahl und Eisen, 1941, vol. 61, Mar. 20, pp. 281–289; Mar. 27, pp. 314–320). The author discusses in detail the fundamentals governing the supply and consumption of heat in the various processes involved in producing iron and steel from ore. Cost calculations and flow diagrams relating to the production of blast-furnace coke, pig-iron and steel are presented, and the effect of the price factor on the proportions of scrap and pig-iron in the steel-furnace charge is dealt with.

The Smelting of Iron Ores by Old and New Methods. R. Durrer. (Stahl und Eisen, 1940, vol. 60, Oct. 3, pp. 877–880). The author discusses the economic aspects of the production of iron in blast-furnaces, in rotary and electric furnaces, and the use of oxygen-enriched blast. The possibility of reducing ores in an electric furnace supplied with current from a brown-coal power-station is examined. Such a process would only be economic in a district where there is no coking coal, where imported coke is too dear and when the brown coal could not be used as a fuel for the direct reduction of the ore. Reference is made to some experiments carried out in 1939 in which coke was burned with pure oxygen in a small shaft furnace producing a high proportion of carbon dioxide in the flue-gases. This proved that it is possible by using pure oxygen to prevent, at least in some degree, the reduction to carbon monoxide of the carbon dioxide which takes place when ordinary air is used for the blast. A calculation is presented from which it is deduced that 1 ton of iron could be produced with a consumption of 350 kg. of coke for reduction and 100 kg. of coke for heating, the former being converted into carbon monoxide by the oxygen from the ore, and the latter being converted to carbon dioxide by oxygen supplied from an external source. The argument is developed that it may soon be an economic proposition to reduce low-grade ore fines in a low shaft furnace using an inferior coke and pure oxygen, or an oxygen-enriched blast.

Form of Sulphur Occurrence in Blast-Furnace Slag. A. E. Martin, G. Glockler and C. E. Wood. (United States Bureau of Mines, 1941, Feb., Report of Investigations No. 3552). The authors report on a study of the form in which ferrous, manganous and calcium sulphides may occur in molten blast-furnace slag and its relationship to the colour of the slag. The glasses obtained by quenching molten slags to which the sulphides were added separately were shown to contain a colloidal phase. The observations made indicated that ferrous sulphide is very slightly soluble in blast-furnace slag of the composition studied, and that the solubility of calcium sulphide in the slag is about 3·6% at a temperature of 1400–1425° C. Slags to which manganous sulphide had been added ranged in colour from light yellow to dark brown and in the sulphur present as sulphide from 0·12% to 1·33%.

Powder Metallurgy Old and New Vistas. J. Wulff. (Metal Progress, 1940, vol. 38, Nov., pp. 665–668, 720). The author reports on the proceedings of the Powder Metallurgy Conference held at the Massachusetts Institute of Technology in August 1940 at which nineteen papers were presented. Brief extracts of these papers, which covered the early history, recent development, scope of existing patents, technique and properties of products, are given.

Ancient Indian Iron Smelting. (Tisco Review, 1941, vol. 9, Feb., pp. 89–90). A brief illustrated account is given of a primitive method of smelting a soft dolerite ore containing about 50% of

iron which is practised in one of the smaller states of Orissa in the Eastern States Agency, India.

Features of Costing and Accountancy in Iron and Steel Works. F. L. Meyenberg. (Iron and Steel, 1940, vol. 13, Mar., pp. 184–186; Apr., pp. 222–226; June, pp. 372–376; July, pp. 402–404; Aug., pp. 423–427; Sept., pp. 450–454; vol. 14, Oct., pp. 7–11; Nov., pp. 102–105; Dec., pp. 132–133; 1941, Jan., pp. 154–157; Feb., pp. 185–188; Mar., pp. 213–217; Apr., pp. 240–243, 252; May, pp. 264–265, 271). In this series of articles the author discusses methods of costing and accountancy suitable for iron and steel works.

FOUNDRY PRACTICE

The Outline of Cupola Control. C. A. Payne. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 64, May 15, p. 331). The author briefly describes the essential points which govern the control of the cupola process.

Test Hot Strength of Molding Sand. N. J. Dunbeck. (Foundry, 1941, vol. 69, Feb., pp. 39–40). The author presents and discusses the results of several series of tests in which the strength at temperatures of 500°, 1000°, 1500°, 2000° and 2500° F., of the following mixtures of moulding materials were determined: (a) Ohio fireclay with 4%, 3·5% and 3·3% of water; (b) western bentonite with Ohio fireclay; (c) southern bentonite with Ohio fireclay; and (d) western with southern bentonite.

Factors in the Production of Sand Castings in High Duty Iron. J. King. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 64, May 8, pp. 315–316). The author discusses the problems of sand control in a foundry making Meehanite castings, and recommends a reduction in the number of moulding sands of different grain size, clay content and permeability which are to be found in many foundries.

A New Method of Producing Chilled Castings. K. Knehans and N. Berndt. (Stahl und Eisen, 1940, vol. 60, Dec. 12, pp. 1132–1134). In order to economise in the amount of special high-carbon iron used in charges for the production of chilled castings, a cupola process has been developed by which the product obtains its additional carbon from the fuel rather than from additions of special iron. The fuel used is a mixture of foundry coke and pitch coke. The latter is much harder and denser than the former. Pitch coke, as produced in Germany, has a sp. gr. of 1·9–2·0, less than 0·8% of volatile matter, about 0·3% of ash, about 98% of carbon and not more than 0·5% of sulphur. Details are given of hardness tests

and analyses on trial chilled castings made by this process using a cupola 1 m. in dia. producing 8 tons of iron per hr. The process is so satisfactory, using 3 parts of foundry coke mixed with 1 part of pitch coke, that the foundry in question has obtained good results since 1937. As much as 70% scrap can be used in the charge in most cases, but it has been found that ingot moulds for 5-ton ingots can be cast from a charge consisting entirely of ingot-mould scrap with no hematite iron at all. The average life of these moulds was 125 casts, as compared with about 130 casts for moulds of hematite iron.

Increasing Silicon with Silvery Iron. B. H. Booth. (Foundry, 1941, vol. 69, Mar., pp. 40, 110, 112). The author gives some details of the practice of adding a certain proportion of silvery pig iron containing 5–12% of silicon to cupola charges in order to produce a high-silicon, low-carbon iron. He also describes a duplex melting practice for making malleable iron in which the cupola charge consists of about 12% of silvery pig iron (silicon 10%), 40% of returns and purchased scrap, and 48% of steel. When melted, the charge is transferred to an electric furnace, in which it is heated to a higher temperature and final adjustments of the composition are made. The finished iron contains approximately carbon 2·50%, silicon 1·20%, manganese 0·40%, phosphorus 0·20% max. and sulphur 0·12% max. Greater flexibility and a faster rate of production are claimed for this process.

Molding Large Diesel-Engine Crankcases. E. Bremer. (Foundry, 1941, vol. 69, Feb., pp. 34–38, 116–118). The author gives particulars of the plant at a large American jobbing foundry and describes in detail the preparation of the mould and cores for casting a large diesel-engine crankcase.

" Book " Molding with Green Sand Cores. E. H. Ballard. (Iron Age, 1941, vol. 147, Mar. 27, pp. 53–56). The author describes and illustrates a method of preparing the cores and mould for casting electric-motor bodies. The cores are made of green sand in two halves in a core-box hinged at one side. The process of bringing the two halves together is similar to closing a book, hence the term " book moulding."

Reducing the Amount of Core Gas. H. W. Dietert. (Foundry, 1941, vol. 69, Mar., pp. 43, 119). The author discusses how the baking temperature and the grain size of core sand affect the quantity and rate of evolution of gas from cores when a casting is poured. The coarser the sand, the greater the permeability and the less will be the amount of the gas; but the heat will travel faster through the core as the permeability increases, and a point is reached at which either the core collapses or the evolution of gas is too rapid for safety. The gas content of a core can also be reduced by baking it at a high temperature, but this involves some reduction in its strength. Some curves are presented which illustrate the relation between the grain size of the sand, the baking

temperature and the percentage of binder to the amount of gas generated.

The Manufacture of Spun Iron Pipes. G. O. Stanley. (Proceedings of the Cleveland Institution of Engineers, 1940, Nov. 25, No. 1, pp. 15–19). Some particulars are given of the De Lavaud centrifugal process of casting iron pipes. The information was given as a commentary to a film showing the process in operation at the works of the Stanton Ironworks Co., Ltd.

PRODUCTION OF STEEL

(Continued from pp. 5 A–6 A)

Research Problems Relating to Steelmaking Processes. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1310 : Metals Technology, 1941, vol 8, Apr.). A list of problems relating to the physical chemistry of steelmaking prepared by the Committee on the Physical Chemistry of Steelmaking of the American Institute of Mining and Metallurgical Engineers is presented. The list was compiled from answers to a questionnaire submitted to a number of metallurgists engaged in industrial and educational work throughout the United States, in order to make available to research laboratories a list of problems the solution of which would aid in creating a better understanding of the steelmaking process.

Contribution on the Metallurgy of the Basic Bessemer Process. W. Geller and A. Wilms. (Stahl und Eisen, 1941, vol. 61, Apr. 3, pp. 337–346). The authors present and discuss the results of some investigations of the metallurgy of the basic Bessemer process, with particular reference to the behaviour of the manganese and oxygen in relation to the formation of slag. The course of the process was followed by analysing samples taken at successive stages in the production of steel in a 20-ton converter using charges differing in manganese content. The nitrogen and phosphorus contents of the steel were in good agreement with those previously reported in technical publications. It was observed that the oxygen content of the steel was less with a charge high in manganese, given the same content of iron in the slag. The authors are of the opinion that for the conditions under which this typical converter was working it is uneconomic to have more than 0.9% of manganese in the charge, and they make suggestions for the pretreatment of high-manganese pig irons.

Metallurgical Observers in Steel Making. E. F. Cone. (Metals and Alloys, 1940, vol. 12, Nov., pp. 625–627). The author describes the organisation and duties of the metallurgical observers employed at three of the steel plants of the Republic Steel Corporation.

Each group of observers at each works consists of from ten to twenty young men whose ages are from twenty-one to twenty-six years. They are distributed over the various departments, and report what they observe on such items as temperatures before and after pouring, slag conditions, soaking-pit temperatures, rolling-mill speeds, &c. These observations have enabled correlations to be established between certain defects or peculiarities in appearance or properties of ingots and rolled steel and the manner in which previous processes have been controlled. Some of these observers are eventually promoted to the position of metallurgist for a particular department.

The Absorption and Evolution of Hydrogen during the Process of Steel Making. S. von Hofsten, Bo Kalling, F. Johansson and O. Knös. (Stahl und Eisen, 1940, vol. 60, Dec. 5, pp. 1101–1107). A German translation is presented of a report on an investigation, sponsored by Jernkontoret, of a study of the influence of the hydrogen content of molten steel upon the refining process. The original report appeared in Jernkontorets Annaler, 1939, vol. 123, No. 10, pp. 485–526. (*See* Journ. I. and S.I., 1940, No. I., p. 233 A).

Controlling Reactions in the Open-Hearth Process. B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1319 : Metals Technology, 1941, vol. 8, Apr.). In this discussion of the various reactions taking place during the open-hearth process of steelmaking, the author distinguishes between the fundamental and the secondary or resultant reactions. He comes to the following conclusions : (1) The most significant reaction is the oxidation of the carbon in the metal, the progress of which determines the oxygen pressure in the slag and in the metal and produces stirring effects ; all of these factors influence the course of the process as a whole ; (2) the control of iron oxide in the slag does not provide a means of controlling the open-hearth process, as this is a secondary rather than a primary factor ; (3) the fundamental variables in the open-hearth process are bath temperature, rate at which ore is added, charge composition and slag basicity ; and (4) the basicity of the slag is an independent variable, and the distribution of manganese, sulphur and phosphorus is only indirectly connected with the progress of the carbon reaction.

On the Emissivity of Liquid Steel. T. Sugeno. (Tetsu to Hagane, 1941, vol. 27, Feb. 25, pp. 59–77). (In Japanese). In a theoretical discussion aided by practical experiments the author examines the methods of measuring the emissivity of a steel bath and the relation between the value obtained, the degree of refinement of the steel and the nature and quantity of the alloying elements present. The conclusions reached include the following : (1) In the open-hearth furnace the emissivity is closely related to the quantity of FeO present in the liquid steel ; (2) in the electric arc furnace there is only a correlation between the emissivity and the FeO content during the final stage of the reduction ; (3) the emissivity of molten

alloy steels is usually higher than that of plain carbon steels; and (4) an increase in the manganese content increases the emissivity of the steel.

Utilization of Manganese in the Steel Industry. B. A. Rogers. (United States Bureau of Mines, 1941, Apr., Information Circular No. 7162). The author reviews the American imports, production and consumption of manganese, and discusses the best methods of utilising the American sources of supply. As far as steelmaking is concerned, the author advocates the use of manganese alloys made from low-manganese ores as the most satisfactory method of compensating for an insufficiency of the customary grade of ferromanganese.

Investigations on the Valuation of Ferro Alloys. H. Siegel. (Stahl und Eisen, 1940, vol. 60, Dec. 12, pp. 1125—1131). The author describes a method of studying the melting characteristics of minerals using an oxy-acetylene welding torch, and its application for examining the behaviour of ferro-tungsten, ferro-molybdenum, molybdenum metal and ferro-vanadium. Lumps of the alloys 40–60 cu. cm. in size were preheated to a light red colour, and the burner was then brought sufficiently near to cause them to melt, and the behaviour of the material was closely observed. Some samples of the alloys were etched and subjected to a metallographic examination, others were analysed, and the quantities and composition of the gases evolved during heating were also determined. In the case of ferro-tungsten, the data obtained are related to the iron/iron-carbide/tungsten and the iron/carbon/tungsten diagrams. The observations made are discussed with particular reference to the behaviour of these alloys when added to a bath of molten steel.

On the Electrode for Arc Furnaces. T. Hayashi. (Tetsu to Hagane, 1941, vol. 27, Feb. 25, pp. 88–98). (In Japanese). The authors report on their study of the composition, specific gravity, porosity, transverse strength, hardness and electrical resistance of synthetic graphite, natural graphite and carbon electrodes with a view to determining the best kind of electrode for use in an electric steel furnace. Of the various electrodes examined, the synthetic graphite type proved to be the best.

Armored Steel. T. W. Lippert. (Iron Age, 1941, vol. 147, Mar. 6, pp. 35–45). The author gives some general information on the " Pluramelt " process of coating carbon steel ingots and slabs with stainless steel and chromium-nickel alloys of various compositions. (*See* Journ. I. and S.I., 1940, No. I., p. 282 A). He also presents data from acid-penetration and deep-drawing tests on vessels made from sheet rolled down from the·coated ingots.

Examination of a High-Sulphur Free-Cutting Steel Ingot. E. Gregory and J. H. Whiteley. (Iron and Steel Institute, 1941, this Journal, Section I.). An ingot of steel of high sulphur content was subjected to a detailed examination in regard to heterogeneity, and an examination of the inclusions in it was made. The experi-

mental evidence recorded in Part I., by Gregory, indicates that the degree of segregation is less than might have been expected and is actually of a similar order to that found to occur in steel ingots of more " normal " sulphur contents. It is shown that, in the ingot examined, the elements which tend to segregate to the least extent are carbon, manganese, phosphorus and nitrogen, and that the elements which exhibit the greatest variation are sulphur, oxygen and hydrogen; the last three elements tend to segregate, but independently, although there is some indication, from both chemical analysis and microscopical examination, of inverse segregation as regards sulphur and oxygen, *i.e.*, a high sulphur content is accompanied by a relatively low oxygen content and *vice versa*. Attention is drawn to the fact that when the oxygen content is low, the inclusions are apparently homogeneous, whereas in regions relatively rich in oxygen the inclusions exhibit duplex structures. It is also shown that the " major " inclusions have spherical or globular forms, indicating some degree of emulsification before the freezing of the steel, and the view is expressed that this has some connection with the excellent rolling properties of the steel.

In Part II. Whiteley describes the examination of the inclusions at three positions in the ingot. As was to be expected, sulphide particles were very numerous. Both large and small consisted of MnS, except in highly segregated areas, where FeS greatly predominated. The coalescence of sulphides has been studied. It is shown that, on heating the steel to within the liquidus-solidus range, the MnS inclusions were replaced by groups of minute particles containing much FeS. In cooling, two distinct arrangements of these particles occurred, both resembling eutectic formations. Owing to the presence of local areas rich in FeS, the diffusion of manganese in the steel up to 1350° C. has been investigated, using both pearlite coalescence and the change of FeS to MnS as indicators. The rate was found to be slow. The fact that steel of this kind rolls well, notwithstanding its very high sulphur content, leads to a consideration of possible factors which influence cracking in casting, on the basis of which an explanation is suggested. Besides the sulphides there was another type of inclusion. It was composed of globules, sometimes very large and often complex in structure. Within them were usually rounded MnS particles and an occasional idiomorphic crystal resembling chromite. Frequently the globules also contained areas of FeO, this compound not being elsewhere observed. The ground-mass in which these inclusions were embedded was eutectiferous in character and translucent owing to a silicate component. Various tests indicated that it belonged to the system fayalite-rhodonite–FeS–MnS–FeO.

Study of the Disappearance of Flakes by Compression. S. Saito and N. Yamamoto. (Tetsu to Hagane, 1941, vol. 27, Feb. 25, pp. 81–88). (In Japanese). The authors studied how the application of pressure at high temperatures causes the disappearance of flakes

in steel bars. They found that a certain minimum pressure was necessary, and that this depended on the temperature, as well as to some extent on the quality and section of the steel. They established that this critical pressure was 40–60 kg. per sq. mm. at 1200° C. and 60–100 kg. per sq. mm. at 1000° C.

Recovery of Special Metals from the High-Speed Steel Scrap. R. Kikuchi. (Tetsu to Hagane, 1941, vol. 27, Feb. 25, pp. 78–81). (In Japanese). The author discusses how tungsten, cobalt and vanadium can be recovered from high-speed steel scrap.

FORGING, STAMPING AND DRAWING

New Forge Shop at Australian Iron & Steel Ltd., Kembla Works. (B.H.P. Review, 1941, vol. 18, Mar., pp. 1–3). An illustrated description is given of the recently completed extensions to the forge shop at the Kembla Works of Australian Iron & Steel, Ltd. There are now four batch and two car-bottom reheating furnaces fired by coke-oven gas, and a 2000-ton hydraulic press in this department. Ingots up to 36 tons can be dealt with, and the shop is at present turning out gun-barrel forgings.

Hot and Cold Heading. A. S. Jameson. (Metal Progress, 1940, vol. 38, Nov., pp. 691–697). The author discusses factors which affect the hot- and cold-heading capacity of steel. He observes that sulphur in amounts up to 0·050% has little effect, but when more than that is present the ability of the steel to be cold-worked is reduced. Phosphorus and silicon act as ferrite hardeners and reduce the cold-working capacity. The alloying elements which decrease the ductility of the ferrite in low carbon steels, in order of decreasing effect, are : manganese, nickel, molybdenum, vanadium and chromium. So as to offset the effect of these elements when considerable pearlite areas are present, the carbide plates are transformed to the spheriod shape by an appropriate heat treatment. The author considers the theories put forward to explain why cold-working a steel increases its resistance to further cold-work, a fact which often makes it necessary to heat-treat parts which have been cold-headed. In the author's opinion there is no doubt that plastic deformation results in a disturbance of the molecular arrangement, with possibly the formation of at least a subcrystalline material which may be called " amorphous-behaving " ; such a material would be in a state of high molecular tension. In general, the most easily cold-worked steel is one containing less than 0·12% of carbon, but it has the disadvantage that it is subject to excessive grain-growth if it is reheated after previous severe cold-work to restore its cold-working capacity. In practice, rivets made from

this material are closed cold, or, if hot riveted, they are heated to above 1650° F. Both bolts and rivets are usually made of 0·15–0·25% carbon steel, the former being annealed at 950–1100° F., and the latter at 1550° F. for riveting cold. Steels with carbon in the 0·25–0·45% range are only used for bolts and rivets when high physical properties are to be obtained by subsequent heat treatment.

Here is the Case for Compression Cold-Riveting. R. S. Osborne. (Steel, 1941, vol. 108, Mar. 17, pp. 64–68, 99, 100, 104). The author discusses the advantages of compression cold-riveting as compared with hot-riveting. These advantages include the following : (1) Cold-compressed rivets are stronger ; (2) a cold-compressed rivet will fill the entire length of the hole, whereas a hot-driven rivet only swells to fill the hole to a depth equal to twice the diameter of the rivet shank ; (3) they are not subject to cooling strains and contraction ; (4) cold rivets can be handled and placed in the holes more rapidly ; (5) there is no expenditure on fuel ; and (6) if there is a thin space between the members being riveted, no collar will form on the rivet shank.

Diversity of Precision Stampings Produced at Worcester Pressed Steel Company. F. A. Westbrook. (Heat Treating and Forging, 1941, vol. 27, Mar., pp. 126–130). The author describes the light and heavy stamping departments and the heat-treatment shop of a Massachusetts company producing a large variety of ferrous and non-ferrous parts.

Recent Developments in Metal Extrusion. A. B. Cudebec. (Mechanical Engineering, 1941, vol. 63, Jan., pp. 16–18). The author presents a general review of the present stage of development of large presses for extruding stainless steels and nickel and other non-ferrous alloys. He compares the advantages and disadvantages of horizontal and vertical machines.

ROLLING-MILL PRACTICE

Roll More Tons—Practical Roll Calibration Calculation. A. E. Lendl. (Blast Furnace and Steel Plant, 1941, vol. 29, Mar., pp. 307–312). The author's article on the improvement of roll design is reproduced. (*See* Journ. I. and S.I., 1941, No. I., p. 159 A).

Bethlehem Doubles Rod-Making Capacity at Sparrows Point. (Wire and Wire Products, 1941, vol. 16, Mar., pp. 175, 199, 200). A brief illustrated description is given of the recently completed extensions to the rod mill at the Maryland Works of the Bethlehem Steel Co. The mill is now capable of a production of 1000 tons in 24 hr.

Rebirth of a Steel Plant. (Steel, 1941, vol. 108, Mar. 24, p. 77). **Follansbee Steel Corporation Modernizes Manufacturing Processes.** (Blast Furnace and Steel Plant, 1941, vol. 29, Mar., pp. 313–315). A brief illustrated description is given of the strip mills of the Follansbee Steel Corporation, where an extensive reorganisation has recently been completed. (*See* Journ. I. and S.I., 1941, No. I., p. 211 A).

Acme Steel Company Operates New Cold Mill. C. A. Richardson. (Blast Furnace and Steel Plant, 1941, vol. 29, Mar., pp. 337–338). The author gives a brief illustrated description of a new 4-stand tandem cold-strip mill which was put in operation by the Acme Steel Co., at Riverdale, Illinois, in 1940. A wide range of speed is available on the first two stands by reason of the change-gear drives fitted to the variable-speed D.C. motors. Automatic shifting entering guides are fitted, so that when narrow strip is being rolled it can be moved across the face of the rolls.

How to Obtain High Eccentricity [*sic*.; Concentricity] in Light-Walled Tubing. R. McLaren. (Steel, 1941, vol. 108, Mar. 24, pp. 78-80). The author gives some particulars regarding the benefit obtained by an American tube manufacturer as a result of changing over from plain brass bearings to taper roller bearings in the mill-stands. The mill is now capable of reducing tubes from 5 in., to $1\frac{3}{4}$ in. in outside dia. and down to 10 gauge without eccentricity or the formation of ridges on the inside wall.

A Cure for Variable-Voltage Ills in Strip Rolling. R. W. Wright. (Steel, 1941, vol. 108, Apr. 7, pp. 76–80, 99). With the increasing delivery speeds of modern cold-reduction tandem strip mills, the ratio of the production speed to the mill-threading speed is of course also increased, and the difficulty consequently arises of synchronising the individual mill-stands during the accelerating, decelerating and threading periods. In the present paper the author describes an electrical control system in which a compensation generator is placed in the armature circuit of each stand motor to compensate for the drop in the internal resistance of this circuit when the motors are running with only a fraction of their rated voltage applied. This control system operates automatically, and enables the correct tension to be maintained on the strip between stands at slow speeds.

Manipulation of Blooms. C. N. Hammill. (B.H.P. Review, 1941, vol. 18, Mar., pp. 6–7). An illustrated description is given of an electrically driven manipulator for turning through 90° blooms measuring 10 in. × $8\frac{3}{4}$ in. and 9 in. × $6\frac{3}{4}$ in. at the continuous billet and bar-mill at the Kembla Works of Australian Iron & Steel Ltd.

New Billet-Cutting Shear. (Iron and Coal Trades Review, 1941, vol. 142, May 30, p. 615). An illustrated description is given of a machine for cutting billets up to $4\frac{1}{4}$ in. square in mild steel, in the cold state. The machine is driven by an 85-h.p. motor mounted on top. The shear-blades are mounted in steel liners attached to the bed and the slide of the machine inside its frame. Gearing

throughout the machine is of cast steel, with continuous double-helical teeth. An automatic hydraulic clamp holds the billet in position for shearing.

A Gage for Measuring the Thickness of Sheet Steel. B.M. Smith and W. E. Abbott. (General Electric Review, 1941, vol. 44, Feb., pp. 125–127). The authors give a detailed description of a magnetic thickness gauge with which the thickness of steel sheets can be measured within 1 mil. for any thickness in the 10–25-mil. range, and within 2 mil. in the 20–45-mil. range. The instrument is small and portable, and has the advantage that it can be used when only one side of the sheet is accessible.

PYROMETRY

A High Sensitivity Radiation Pyrometer. N. E. Dobbins, K. W. Gee and W. J. Rees. (British Steelmaker, 1941, vol. 7, Mar., pp. 53–54). The authors give the constructional details and working principles of a photo-electric radiation pyrometer which they have developed. This description appeared previously in Transactions of the British Ceramic Society, 1940, vol. 39, Aug., pp. 253–257. (*See* Journ. I. and S.I., 1941, No. I., p. 11 A).

Location of Faults in Pyrometer Equipment. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, No. 28, pp. 41–46). The methods of finding and repairing faults in thermocouples and temperature-measuring equipment for heat-treatment furnaces are described.

HEAT TREATMENT

(Continued from pp. 9 A–13 A)

Additions to Bethlehem's Electric Heat-Treating Facilities. (Metals and Alloys, 1941, vol. 13, Mar., pp. 305–308). **Bethlehem Revamps Electric Heat Treating.** (Iron Age, 1941, vol. 147, Mar. 13, pp. 60–63). An illustrated description is given of the heat-treatment plant of the Bethlehem Steel Co., where a reorganisation and extensions have recently been completed. (*See* p. 12 A).

A Large Gas-Fired Installation for the Heat Treatment of Forgings. (Metallurgia, 1941, vol. 23, Apr., pp. 161–163). An illustrated description is presented of a modern gas-fired heat-treatment plant for small forgings. (*See* p. 12 A).

Improved Radiant-Tube Strip Annealing Furnace. (Steel, 1941, vol. 108, Apr. 14, pp. 66–69). An illustrated description is given of an annealing plant for steel strip which consists of three bases, three cylindrical furnaces heated by burning a deoxidising gas

formed by the partial combustion of natural gas, and one furnace cover.

Making Sheet Steel to Fit the Requirements. R. S. Burns. (Metal Progress, 1941, vol. 39, Mar., pp. 303–306, 366). The author discusses the influence of the final rolling and annealing processes on the mechanical and structural properties of steel sheet. He explains the purposes of normalising and stress-relief low-temperature annealing, and illustrates the effects of different cooling rates, and of different degrees of cold-reduction before annealing, on the microstructure. He then demonstrates the effects of different degrees of cold-reduction on the tensile strength and elongation of steel sheet by reference to several series of stress-strain diagrams. In conclusion the effect of ageing at room temperature and of accelerated ageing at higher temperatures after temper-rolling in raising the yield point and lowering the ductility is discussed.

Electrical Heat Treatment of Rivet Studs. L. C. Conradi. (Metals and Alloys, 1941, vol. 13, Mar., pp. 284–287). The author gives brief descriptions of two methods of heat treating small steel rivets used in the manufacture of electric accounting machines. The heads of these rivets are case-hardened, but the shanks have to be left soft. In one method the rivets are first hardened all over, and the ends are then softened by selective annealing in which the heat is applied by placing the shank between the jaws of an electric contact resistance heater. In the second method the rivets are first carburised, but not hardened ; they are then placed in recesses in a " transite " disc (composition not stated) with their shanks protruding ; the disc is placed for a few seconds within the coil of an H.F. induction heater and then quenched, with the result that the heads are hardened and the shanks remain soft.

MACHINING

Tool Angles for Steel Cutting with Carbides. H. S. Wilcox. (Iron Age, 1941, vol. 147, Mar. 20, pp. 39–45). The author presents and discusses the results of tests made to determine the power required to cut steel S.A.E. 1035 with twelve different combinations of cutting angles on cemented carbide tools. The test data are given in numerous tables and graphs. The general conclusions reached were as follows : (1) A large side rake angle (30°) is beneficial in reducing power consumption and tool breakage ; (2) a negative back slope does not materially increase the power consumption as is generally supposed ; (3) the power consumption does not increase in direct proportion with increases in the rate of feed and cutting speed ; (4) machining with cemented carbides at high speeds consumes more power than is generally supposed ; (5) the tool load

reduces the spindle speed considerably below the free running speed set on the dial; and (6) an appreciable amount of power is required to curl chips.

Speciality of Steel and Cast Iron in Working Revealed in Cutting Test. K. Hosi. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. IV-7–IV-15). (In Japanese). The author reports on an investigation of the machining characteristics of steel and cast iron in which he compares the change in contour of the cutting tool when rough-turning the two materials and the effect of this change on the force required to continue the cut.

Pictorial Presentation of Operations on High-Explosive Shell from Forging Shop to Loading Plant. A. F. Macconochie. (Steel, 1941, vol. 108, Mar. 17, pp. 56–63). The author describes briefly with many illustrations twenty-five consecutive machining and fitting operations for manufacturing 75-mm. high-explosive shells from rough forgings. A table is also given of the machines used, their cost, the cost of electric equipment, tools and gauges, and the time taken in the performance of each operation.

PROPERTIES AND TESTS

Selection of Steels as Affected by Tensile Properties. G. T. Williams. (Metal Progress, 1941, vol. 39. Mar., pp. 323–329). The author explains the terms tensile strength, elastic limit, yield point, proof load and ultimate stress, and demonstrates with the aid of diagrams how these properties vary in steel specimens with the angle between the axis of the test-piece and the direction of rolling of the steel of which it is made.

On the Relation between Tensile and Torsional Yield Points. T. Sato and M. Itihara. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-64–I-67). (In Japanese). The authors carried out tensile and torsional tests on specimens of low-carbon steel with the object of establishing a relation between the amounts of permanent deformation under the two types of stress. Stress-strain diagrams were plotted from the data obtained, and it was established that the permanent set in torsion was 1·5 times that in tension. As the tensile yield point is generally defined as that stress which causes 0·2% permanent elongation, the authors suggest that the torsional yield point should be defined as the amount of tensile stress causing 0·3% permanent elongation.

Photoelastic Analysis of Two- and Three-Dimensional Stress Systems. B. Fried and R. Weller. (Ohio State University Studies, 1940, vol. 9, July, Engineering Experiment Station Bulletin No. 106). In Part I. of this treatise on the examination of stress systems by means of polarised light the authors explain the principles

of the polariscope and the method of interpreting the stress patterns of two-dimensional stress systems. In Part II. they discuss the most suitable shape for tensile-test specimens for examination by this method. Part III. they devote to the study of stresses in models of beams subjected to a bending stress, and finally in Part IV. they explain the three-dimensional photo-elastic method of determining the manner in which stresses vary in different planes in a solid body.

White Spots in Fractures and Transverse Fissures in Rails. H. O'Neill. (Metallurgist, 1941, vol. 13, Apr. 25, pp. 12–15). Recent studies of broken test-pieces of weld metal have been made to trace the cause of certain " white spots " or " fish eyes " seen on the fracture faces. In the present paper the author considers some observations on rails which have broken transversely during service, and have also revealed a large bright patch within which was a granular silvery spot or a dark oxidised spot. From his own work and a review of that of other investigators he summarises the types of fracture and their probable causes in the following Table :

Nature of Fracture.	Type of Deformation.	Reputed Prime Cause.
Hair-line cracks.	Static-tensile or bending.	Hydrogen.
Fish eyes in weld metal.	,,	Inclusions and/or hydrogen.
White spots in railway tyres.	,,	Inclusions (hydrogen not determined).
White spots in castings.	,,	Hydrogen.
White spots in weld metal.	Fatigue	Inclusions or weld crack.
White spot in case-hardened or nitrided steel.	,,	Combination of stresses producing local peak below surface.
Transverse fissures in rails :	,,	
(a) with silvery spot.		Shatter cracks (due to hydrogen.
(b) with oxidised spot.		Inclusions or combined stress peak.

Progress in the Detection of Defective Rails. C. W. Gennet, jun. (Journal of the Western Society of Engineers, 1940, vol. 45, Dec., pp. 292–300). The author reviews some of the improvements which have been made to the Sperry rail-defect detector car during the last ten years. These improvements include : (1) The searching unit is now suspended loosely from the brush-carriage frame and rides the rail on small wheels, thus enabling it to follow the minute variations in the rail surface ; (2) the searching unit consists of four staggered coils, and covers a larger area of the rail head ; (3) the coils are arranged so that the rail is energised by two circuits one slightly in advance of the other ; (4) the device for making a small sharp paint-mark at the position of the defect has been improved ; and (5) methods of distinguishing more clearly between the chart indications of surface defects and internal defects have been applied. Some data on the amount of testing done in the United States by this method and the frequency of faults are also given.

The Fatigue Test of Steel under Combined Bending and Torsion. T. Nisihara and M. Kawamoto. (Transactions of the Society of Mechanical Engineers Japan, 1940, vol. 6, Aug., pp. I-8–I-11). (In Japanese). The authors describe an improved form of fatigue-testing machine, and discuss the results obtained when using it for bending- and torsional-fatigue tests on specimens of an annealed 0·34% carbon steel.

Fatigue Tests on Iron, Steel and Light Alloy Chiefly under Bending. A. Ono. (Transactions of the Society of Mechanical Engineers Japan, 1940, vol. 6, Aug., pp. I-26–I-35). (In Japanese). The author makes a theoretical study of the effect of vibration on the determination of fatigue strength with a rotating-bend type of machine, and then describes a practical investigation of the fatigue limit of a number of special steels, cast iron and light alloys.

Some Experiments on the Fatigue of Steel. T. Nishihara and M. Kawamoto. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-47–I-51). (In Japanese). The authors report on an investigation of the effect of applying a static tensile stress to specimens of a 0·34% carbon steel while they are being subjected to torsional fatigue tests. It was found that with a static tensile stress of less than 10 kg. per sq. mm. the fatigue limit remained unaffected, but the fatigue strength of the material increased slightly when the tensile stress was more than 12 kg. per sq. mm.

Study on the Fatigue Strength of Low-Carbon Manganese Structural Steels. A. Tagawa. (Tetsu to Hagane, 1941, vol. 27, Jan. 25, pp. 9–34). (In Japanese). The author describes an investigation undertaken with the object of developing a structural manganese steel with a high fatigue strength. Fatigue tests were carried out on series of specimens of open-hearth steel containing carbon 0·10–0·36% and manganese up to 1·56%, and crucible steel containing carbon 0·10–0·37% and manganese up to 2·34%. The results are shown in numerous tables and diagrams. It was observed that, for a given carbon content, the open-hearth steel required a higher manganese content than the crucible steel to develop the same fatigue strength.

Commercial Aspects of Hardenability Tests. W. E. Jominy. (Metal Progress, 1940, vol. 38, Nov., pp. 685–690). The author presents and discusses the results of several series of end-quench hardness tests (*see* Journ. I. and S.I., 1940, No. I., p. 40 A), and describes how the test data are applied to assist in the selection of suitable steels for making automobile gears and shafts of various sizes.

Hardenability of Shallow-Hardening Steels. O. V. Greene and C. B. Post. (Society of Automotive Engineers : Heat Treating and Forging, 1941, vol. 27, Mar., pp. 120–121). The authors describe a test for determining the hardenability of shallow-hardening steels. In this test a round, tapered bar is prepared 5 in. long $\frac{1}{4}$ in. in dia. at one end and $1\frac{1}{4}$ in. in dia. at the other ; this is heated

to about 1450° F. and quenched in brine; it is then ground until the longitudinal axis is exposed, and Rockwell hardness tests are made along this axis. Such a test is capable of clearly indicating slight differences in the hardenability of shallow-hardening steels.

Wear and Scuffing of Cylinder Bore Irons. P. S. Lane. (Metal Progress, 1941, vol. 39, Mar., pp. 315–320). The author describes a form of wear test in which flat pieces of cast iron are held down by weighted levers against a revolving drum and the loss in weight of metal in a given time is determined. This test is then applied to the determination of the relative wear-resisting properties of different parts of automobile cylinders, and the results obtained are related to the thickness and microstructure of the casting.

Second Report on the Study of Abrasion Mechanism of Metals at the Japan Society for the Promotion of Scientific Research. K. Asakura. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-1–I-2). (In Japanese). The author reports on an investigation of the mechanism of the abrasion occurring between two sliding metal surfaces. He differentiates between the mechanical breakdown caused by hard peaks on one surface piercing softer peaks on the other surface and that caused by the fusing and oxidising of the metal due to the heat generated by friction at the points of contact.

Researches on the Mechanism of Wear—Report II. Similarities between the Phenomena of Wear and the Destructive Phenomena of Convexity of Cast Iron when a Particle Lies between Two Convexities. M. Okoshi and H. Sakai. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-2–I-16). (In Japanese). In order to investigate certain aspects of the phenomenon of wear, the authors studied the nature of the fractures caused when forces were applied in opposite directions to pairs of cast-iron teeth with a hard, round particle between them. The effect of varying the apex angle of the teeth and the particle diameter were determined.

Influence of Atmospheres on the Wear of Steel. S. Saito and N. Yamamoto. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-16–I-24). (In Japanese). The authors studied the influence of the surrounding gas on the wear of pairs of steel discs 40 mm. in dia. and 10 mm. thick revolving at different speeds with their edges in contact. The tests were carried out in nitrogen, hydrogen, carbon dioxide, ammonia and in a vacuum. It was observed that : (*a*) The wear in a vacuum of 0·03 mm. of mercury was twice that in air ; (*b*) the wear in hydrogen and nitrogen was also twice that in air and the worn surfaces became very rough ; (*c*) in carbon dioxide the wear was less than in air, the surfaces remained smooth and became covered with a black powder ; and (*d*) in ammonia, 0·72% carbon steel wore rapidly as in hydrogen, whilst 0·35% carbon steel only showed a slight loss in weight at a low pressure, the loss increasing as the pressure of the ammonia was increased.

Study on Wear with the Electron Diffraction Method. I. Iitaka and T. Tokumitu. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-24–I-27). (In Japanese). The authors describe their investigation by the electron-diffraction method of the surface structure of Armco iron and cast iron after grinding with abrasives of various degrees of fineness.

On the Mechanism of Scratch-Abrasion. M. Masima. (Transactions of the Society of Mechanical Engineers, Japan, 1940, vol. 6, Nov., pp. I-27–I-29). (In Japanese).

High-Temperature Tensile Tests of Welded 18-8. O. H. Henry and A. L. Huber. (Welding Journal, 1941, vol. 20, Mar., pp. 135-S–137-S). The authors describe an investigation in which a comparison was made of the tensile strength of specimens cut from welded and unwelded specimens of $\frac{3}{4}$-in. 18/8 stainless steel plate at various temperatures in the range 74–1600° F. In short-time tests at elevated temperatures it was observed that the tensile strength of welded specimens was equal to that of unwelded specimens ; the yield strength of the former was slightly higher than that of the latter, owing to the lower ductility of the weld metal, and the elongation of the former was about 25% less than that of the latter.

The Present Status of the Low-Alloy, High Strength Steels—A Survey. E. F. Cone. (Metals and Alloys, 1941, vol. 13, Mar., pp. 273–283). The author presents a survey of a number of American low-alloy high-strength steels, giving tables of their composition and physical properties. The steels are divided into two main groups. The first one includes a number of S.A.E. steels and some steels developed to meet A.S.T.M. specifications, whilst the second consists of those more recently developed by individual manufacturers who have given them trade names. The following Table shows the names and the amounts of the important elements in the second group of steels :

Name.	C. %.	Mn. %.	Cu. %.	Ni. %.	Other Elements.
Cor-ten	0·12 max.	0·1–0·5	0·3–0·5	0·55 max.	Cr 0·5–1·5
Man-ten	0·30 max.	1·1–1·6	0·2 min.	...	...
Yoloy	0·05–0·35	0·3–1·0	0·8–1·1	1·5–2·0	...
RDS-1	0·12	0·5–1·0	0·5–1·5	0·5–1·25	...
RDS-1A	0·30 max.	0·5–1·0	0·5–1·5	0·5–1·25	...
Hi-Steel	0·12 max.	0·5–0·7	0·9–1·25	0·45–0·65	...
Armco High Tensile	0·12 max.	0·20 min.	0·35 min.	0·50 min.	...
Jal-Ten	0·35 max.	1·25–1·75	0·40 max.	...	...
Konik	...	...	0·10–0·30	0·3–0·5	Cr 0·07–0·30
Granite City HS-1	0·14	0·7–0·9	0·25–0·30	...	Cr 0·12
Mayari R	0·12 max.	0·5–1·0	0·5–0·7	0·25–0·75	Cr 0·20–1·00
A.W. Dyn-El	0·11–0·14	0·5–0·8	0·3–0·5	...	...
N-A-X High Tensile	0·10–0·18	0·60–0·75	0·25 max.	0·10–0·25	Zr 0·10–0·15 Cr 0·50–0·65
Otiscoloy	0·12 max.	1·00–1·35	0·50 max.	0·10 max.	Cr 0·10 max.

Properties and Heat Treatment of 9 Per Cent. Cr 1·5 Per Cent. Mo Cast Steels. F. B. Riggan. (Metals and Alloys, 1940, vol. 12, Nov., pp. 615–619). An American company manufacturing pipe fittings for oil refineries is now making increasing use of a cast steel containing 9% of chromium and 1·5% of molybdenum as an intermediate alloy between 18/8 stainless steel and steel containing 5% of chromium and 0·5% of molybdenum. In the present paper the author discusses the mechanical properties and corrosion-resistance of this steel after various forms of heat treatment, and compares the results of laboratory and field tests with those obtained with carbon steel and 5% chromium steel.

A New Die Steel for Stamping Short Runs. L. Sanderson. (Heat Treating and Forging, 1941, vol. 27, Mar., pp. 135, 144). The author gives particulars of a new chromium-vanadium-molybdenum steel for making dies for the manufacture of small numbers of cold-formed or stamped parts. (See Journ. I. and S.I., 1941, No. I., p. 226 A).

Free License Offered on *DBL* High Speed Steel. (Iron Age, 1941, vol. 147, Mar. 13, pp. 68–69). In order to conserve the supply of tungsten and to assist in the manufacture of weapons and armaments, an American company has offered to grant a licence for the manufacture, free of royalty, of *DBL* high-speed steel. A typical analysis of this steel is : Carbon 0·80%, tungsten 5·25%, chromium 4·00%, vanadium 1·50%, and molybdenum 4·00%. It is claimed that the cutting properties of this steel are equal to those of high-speed steel containing 18% of tungsten.

METALLOGRAPHY AND CONSTITUTION

An Exposure Meter for Photomicrography. H. S. Jerabek and W. W. Wolf. (Metal Progress, 1941, vol. 39, Mar., pp. 330–332). The authors describe a modification of a popular extinction-type exposure meter which enables it to be used for photomicrography.

Grain Orientation as Exposed by X-Rays. S. Coppick. (Wire and Wire Products, 1941, vol. 16, Mar., pp. 159–163). The author explains by simple analogies the theory of the method of studying the grain orientation in steel wire at various stages in the drawing by X-ray diffraction process.

Thermal Characteristics of Some Low Alloyed Steels. N. A. Ziegler. (Journal of the Western Society of Engineers, 1940, vol. 45, Dec., pp. 277–281). The author describes the transformations which occur during the cooling of three low-alloy nickel-chromium-molybdenum steels, and discusses the relation between these transformations and the contraction and expansion which takes place.

Transformations and Mass Effect in Nickel-Chromium and Nickel-Chromium-Molybdenum Steels. H. Shimoda. (Tetsu to Hagane, 1941, vol. 27, Jan. 25, pp. 1–8). (In Japanese). The author reports on an investigation of the transformation and critical cooling rates of specimens of nickel-chromium and nickel-chromium-molybdenum steels 20 to 300 mm. in dia.

CORROSION OF IRON AND STEEL

Carbon Monoxide as an Inhibitor for Stainless Steel. H. H. Uhlig. (Industrial and Engineering Chemistry, Industrial Edition, 1940, vol. 32, Nov., pp. 1490–1494). The author discusses the value of carbon monoxide as an inhibitor to prevent the corrosion of 18/8 stainless steel in dilute hydrochloric acid. He presents data on the quantitative behaviour of the gas as an inhibitor in hydrochloric acid of various concentrations and at different temperatures, and explains the mechanism of the inhibition.

Contribution to Our Knowledge of the Corrosion of Steel Pipes in Clayey Soils in the Absence of Stray Currents. H. Stäger and W. Bédert. (Schweizer Archiv für angewandte Wissenschaft und Technik, 1940, vol. 6, Nov., pp. 306–313). After a general survey of existing knowledge of the corrosion of buried metals, the authors describe their investigation of the corrosion of a welded-steel hydraulic main conveying water to a power-station in Switzerland. The pipe had been buried in clayey soil and, after 35 years service, its walls, originally 5 mm. thick, were found to be perforated mainly on the upper side. By means of laboratory experiments the authors were able to reproduce the pitting observed in the field, and to show that it was due to differential aeration.

ANALYSIS

Carbon Train for Control Analysis. L. Singer, H. J. Stark and J. A. Krynitsky. (Industrial and Analytical Chemistry, Analytical Edition, 1941, vol. 13, Feb., pp. 115–117). The authors describe some modifications of the carbon train as usually set up for determining the carbon in steel, the object being to shorten the time required, so that the results may be applied to the control of the steelmaking process.

The Determination of Molybdenum in Steel. P. Klinger. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Oct., pp. 157–177). After reviewing the known methods for determining the molybdenum in steel, the author critically examines a number of the gravimetric, colorimetric and volumetric processes, and discusses

the influence of the presence of copper, tungsten, vanadium, chromium, nickel, cobalt and zinc on the various methods of determining molybdenum. He also reviews the potentiometric, photometric, spectrum-analytical and polarographic methods of determining molybdenum in specimens of steel containing more than one alloying element. The conclusions drawn from this survey are : (1) Precipitation under pressure is not essential, but this method is very reliable ; (2) of the gravimetric methods, precipitation with sulphuretted hydrogen in an acid solution and weighing as trioxide, and the lead molybdate process after precipitation as sulphide are specially recommended ; (3) titration with potassium permanganate gave accurate results, but titration with ferric chloride and methyl blue was unsatisfactory ; and (4) colorimetric processes with potassium thiocyanate and stannous chloride or with phenylhydrazine were good practical processes whilst the results with the xanthogenate process were unreliable. The study of the effects of other alloying elements mentioned above showed that, when copper was present, the usual gravimetric processes had to be modified, but this was not necessary with the lead-molybdate process. The other elements mentioned above had no effect, except with processes involving precipitation in an alkaline solution. The examination of potentiometric processes demonstrated their reliability. The photometric method of analysis is a practical one and is specially suitable for rapid determinations. The reduction process, using stannous chloride, needs very great care.

On the Determination of the Fixed Nitrogen in Carbon and Alloy Steels. Part II. H. Kempf and K. Abresch. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 255–259). Continuing their study of methods of determining nitrogen in steel (*see* Journ. I. and S.I., 1940, No. II., p. 77 A), the authors report on an investigation undertaken with the object of reducing the time required for determining the nitrogen in steel. They found that, provided the steel would dissolve in boiling dilute sulphuric acid without any residue containing nitrogen, a determination could be made in 20–25 min. A little longer was required for alloyed steels complying with the above condition. The process is described in detail with a diagram of the apparatus, and the authors claim that the method fulfils the steel producer's need for a rapid and accurate method of making nitrogen determinations during production.

Polarographic Determination of Nickel and Cobalt. J. J. Lingane and H. Kerlinger. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, Feb., pp. 77–80). The authors describe the conditions under which nickel and cobalt can be determined simultaneously by the polarographic technique with a dropping mercury electrode. Previously an ammoniacal supporting electrolyte has been recommended for the simultaneous polarographic determination of nickel and cobalt, but the authors have

found that with this the accurate determination of nickel was not possible when a large amount of cobalt was present. With the method now described the authors have found that an excellent separation of the nickel and cobalt waves is obtained with thiocyanate or pyridine as the supporting electrolyte.

The Rapid Spectro-Chemical Analysis of Steels at Large American Plants. H. Kaiser. (Stahl und Eisen, 1941, vol. 61, Jan. 9, pp. 35–39). The author describes the spectrum-analysis laboratory at the Ford plant at Detroit, giving full details of the general layout, the instruments, the dark-room, the method of evaluating the spectrograms and the speed and accuracy with which the results are obtained.

On the Spectrographic Determination of Low Aluminium and Alumina Contents in Steel and Iron. O. Schliessmann. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Nov., pp. 211–216). The author points out the importance of being able to determine very low percentages of aluminium in steel, and of the ability to determine separately the amounts present in the metallic state and as oxides. He describes in detail the spectrum-analysis procedure which he developed for this purpose, and discusses the results obtained with it on a large number of samples.

Colorimetric Determination of Phosphorus in Iron Ore. H. H. Willard and E. J. Center. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, Feb., pp. 81–83). The authors describe a modification of Misson's colorimetric method for the determination of phosphorus in iron and steel by converting it into a yellow complex phosphovanadomolybdate. The modified method is intended for the determination of phosphorus in iron ores which are higher in silica than irons and steels. It was necessary to find a reagent which would completely remove the silica as well as the yellow colour of ferric iron. In the method described the ore is dissolved in hydrochloric acid and the solution is evaporated almost to dryness ; perchloric acid is then added, which dehydrates the silica and facilitates separation by filtering. The resulting ferric perchloric solution is practically colourless and its acidity is correct for the formation of the yellow complex.

Oxide Analysis in Iron Ore Reduction Problems. T. L. Joseph, F. W. Scott and M. H. Kalina. (Blast Furnace and Steel Plant, 1940, vol. 28, Oct., pp. 975–978 ; Nov., pp. 1073–1077). In the first part of this article the authors discuss how the physical characteristics of iron ores, such as their absolute size, the uniformity of size and porosity, affect the blast-furnace process. In the second part they describe methods of making the following determinations (1) The ferrous and ferric oxides in reduced or partly reduced ores ; (2) the metallic iron in partly reduced ores and residues ; and (3) the silica, alumina and manganous oxide in ore.

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REFRACTORY MATERIALS

Specific Heats of Chrome and Magnesia Refractories. G. E. Seil, F. G. Heck and H. A. Heiligman. (Journal of the American Ceramic Society, 1941, vol. 24, June, pp. 204–210). The authors describe the apparatus and procedure adopted for determining the specific heats of samples of the three following refractory materials : (1) A chrome ore prepared by heat-treating crude chrome ore at 1870° C. in an oxidising atmosphere in an oil-fired rotary kiln ; (2) chrome ore prepared as in (1) then ground and thoroughly mixed with crystallised magnesia and briquetted and fired at 1870° C. to form a material in which each grain of recrystallised chromite was completely surrounded by crystallised forsterite ; and (3) a magnesite ore prepared by heat-treating a domestic magnesite ore in a rotary kiln at 1730° C. The specific heats were determined by heating a weighed sample of the material to a definite temperature, dropping it into a weighed amount of carbon tetrachloride in a calorimeter and measuring the increase in the temperature of the liquid. The analyses of the materials and the test data and results are given in tables and graphs. It was found that, under the conditions described, the mean specific heats of the three materials between 25° and 850° C. expressed in calories per gram per degree centigrade were : (1) 0·235 ; (2) 0·225 ; and (3) 0·283. An extensive bibliography is appended.

Silicon Carbide and Its Use as a Refractory Material. A. C. Lea. (Transactions of the British Ceramic Society, 1941, vol. 40, Apr., pp. 93–115). After describing methods of manufacturing a synthetic silicon carbide with an empirical formula SiC, the author discusses its physical, chemical and heat-resisting properties, the methods of manufacturing bricks and shapes of silicon carbide, the refractory properties of the bricks and their application in the metallurgical, ceramic and gas-producing industries. A bibliography with 181 references is appended.

A Comparison of Refractories for Cupola Service. J. A. Bowers and J. T. MacKenzie. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 193–200). The authors present data representing a comparison of the cost of lining and repairing the melting zones of three different sizes of cupola using two types of natural silica stone and 29%-alumina firebricks. Two of the cupolas were round (21 in. and 54 in. in dia., respectively), and the third was link-shaped, measuring 102 in. × 72 in. The tests were conducted during a regular day's production at a large foundry making cast-iron pipes. The results showed that each of the three

refractories had its particular advantages in meeting certain re quirements of the foundry, but on a 16-hr. run the firebrick lining was the most economical.

Experiences with Ribbed Arches on Large Electric-Arc Furnaces P. Bremer. (Stahl und Eisen, 1940, vol. 60, Aug. 29, pp. 763–764). The author discusses the factors affecting the life of the roofs of electric-arc furnaces and points out the advantages which have accrued from the use of ribbed arches, especially for large furnaces. The design of a ribbed roof which has given excellent service at the works of the Bochumer Verein is described and illustrated. He suggests that refractory brick makers should make great efforts to produce a pure magnesite brick with a high thermal-shock resistance which would be suitable for electric-furnace roofs.

FUEL

(Continued from pp. 35 A–37 A)

Viscosity of Coal-Ash Slags. P. Nicholls and W. T. Reid. (Transactions of the American Society of Mechanical Engineers, 1940, vol. 62, pp. 141–151). The authors describe a viscometer for measuring the viscosity of coal-ash slag at temperatures up to 2900° F. Investigations with the apparatus described show that for most compositions of coal ash there is a distinct liquidus point. A number of temperature-viscosity curves and viscosity/slag-composition diagrams for coal-ash slags are presented.

A Comparison of the Thermal-Balance Characteristics of Integrated Iron and Steel Works. F. Wesemann. (Stahl und Eisen, 1940, vol. 60, Aug. 15, pp. 717–724). The author has studied the thermal balances of a number of integrated iron and steel works and the relationship between these balances and the consumption of raw materials. He distinguishes between the gross and the net consumption of heat, the former representing the total quantity of heat received by the works, and the latter the sum of the quantities of heat actually consumed in the various departments. The most important factor in the heat economy is the consumption of blast-furnace coke per ton of steel produced. It is noted that the consumption of solid fuel, blast-furnace gas and coke-oven gas debited to separate departments such as steel furnaces, rolling mills and power production varies greatly at different works. Power production is almost entirely based on blast-furnace gas as a fuel. The points brought out in the author's discussion show that a close study of the relationship between heat economy and raw-material economy is of the very greatest importance in the planning of the production and allocation of power in an iron and steel works.

The Gas Turbine in the Iron and Steel Works. M. Schatt-schneider. (Stahl und Eisen, 1941, vol. 61, May 8, pp. 465–473). The author describes the changes in the design of large gas turbines as developed by Brown, Boveri & Cie., A.-G. and how they can be used in conjunction with Velox steam boilers and supercharged blast-furnace blast heaters. He also discusses the return on capital outlay and the fuel and maintenance costs.

Some Recent Problems in Coal Preparation and Washing on the Lewis and Marks Group of Collieries. T. Coulter. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1941, vol. 41, Mar., pp. 314–346 ; Journal of the South African Institution of Engineers, 1941, vol. 39, Apr., pp. 230–262). The author selects and examines certain problems of coal preparation which have actually arisen in the South African coalfields during the past five or six years, and gives a broad outline of the methods adopted in dealing with questions of plant design and layout, and the system of cleaning finally selected to meet the requirements of each case.

How Far is the Proximate Analysis a Reliable Guide to Coal Behaviour? J. G. Bennett. (Journal of the Institute of Fuel, 1941, vol. 14, June, pp. 175–183). The author discusses in what measure the proximate analysis of a coal, *i.e.*, the determination of its moisture, volatile matter, fixed carbon and ash, may be taken as a guide to its behaviour in coke ovens and in hand- and mechanically-stoked boilers. It is shown that for the rough-and-ready conditions of hand-firing bituminous coal, the volatile content as determined by almost any method is a useful guide, but for the more exacting conditions of modern combustion appliances the volatile matter has only a very relative value and will sooner or later have to be superseded by more reliable tests. Accurate results can only be expected if the procedure for determining the volatile matter laid down in British Standard Specifications is followed with care. Diagrams purporting to show a relationship between the volatile matter and other properties of the coal are interesting in that they show general changes which coals undergo as they increase in rank, but have little or no value in helping to predict the behaviour of coals from their proximate analyses. The author's general conclusion is that, with up to 26% volatile matter, some correlation with the other properties can be made from the volatile matter, provided that the coal is a bright unoxidised one, a fact which is not revealed by the volatile determination alone, but by the complete analysis ; beyond 26%, the volatile matter appears to be of very little use for an accurate prediction of the properties. Since, however, the conditions of the practical utilisation of coal vary so enormously, it is necessary to supplement analytical methods by *ad hoc* laboratory tests appropriate to the actual conditions of practice.

Effects of Storage and Oxidation of Coal upon Coking Properties. L. D. Schmidt. (Eastern States and Chicago District Blast Furnace

and Coke Oven Association : Iron and Steel Engineer, 1941, vol. 18, Mar., pp. 64–70). The author presents and discusses data relating to nine different American coals which show how their coking properties are affected by oxidation and conditions of storage. He finds that, other conditions being equal, the length of time that a coal can be stored in air without serious deterioration of its coking properties depends on : (*a*) the characteristic rate of oxidation of the coal, *i.e.*, its rate of consumption of oxygen under standard conditions ; and (*b*) its sensitivity to oxygen, *i.e.*, the amount of oxygen the coal can consume without loss of coking power. High-volatile coals, in general, show high characteristic rates of oxidation, but unless they are also exceptionally high in oxygen content, this high rate of oxidation is more than counter-balanced by the fact that these coals can consume relatively large amounts of oxygen without harm to their coking power. In conclusion the author recommends that : (1) Coke-oven operators should determine the effect of various methods of storage upon the amount of oxygen in the air inside large heaps of coal ; and (2) the agglutinating-value test be used to measure the extent of the oxidation of stored coking coals.

Assessing the Coking Value of Coal. R. A. Mott and C. E. Spooner. (Year-Book of the Coke Oven Managers' Association, 1941, pp. 122–141). The authors discuss the important factors influencing the assessment of the coking value of a coal. They show that a coal band can be drawn for British coals using the calorific values as abscissæ and the volatile matter calculated on a dry mineral-matter-free basis as ordinates, and that this band can be divided conveniently into groups. The relationship between volatile matter and ultimate analysis, and between calorific value and ultimate analysis is deduced from fundamental bases, and lines for equal carbon, hydrogen and oxygen can be superimposed on the coal band. The data presented enable coking coals to be classified and a guide given to the yields of by-products and to special types of coal likely to be dangerous to coke-oven walls.

Notes on the Softening of Coal. C. A. Seyler. (Journal of the Institute of Fuel, 1941, vol. 14, June, pp. 195–196). The author explains the terms " softening," " melting," " plasticity," " fluidity ratio " and " viscosity ratio," and appeals to coal chemists to define more clearly the terms they use and to study the new science of rheology ; or the study of flow, which has arisen since the development of the plastics industry.

Notes on the Mechanism of the Carbonization Process, with Special Reference to the Formation and Prevention of Coke Sponge. T. Biddulph-Smith. (Year-Book of the Coke-Oven Managers' Association, 1941, pp. 165–180). The author discusses the formation of two kinds of coke sponge along the top of the coke in a coke oven. He calls these α-sponge and β-sponge respectively. The former is the sponge in the upper part of the vertical coke

fracture consisting of a residue from the distillation of liquid hydrocarbons; the latter consists of puffed-up coke found at the top of the coke charged. He describes a number of tests in the laboratory and with full-size ovens which led to the following conclusions: (1) The two forms of sponge are produced during carbonisation by entirely different conditions; (2) α-sponge is a distillation residue of aliphatic oils evolved from the coal side of the plastic layer; (3) increasing the moisture content of the coal, or adding steam, removes these excess oils at the necessary low temperature, thus preventing the formation of α-sponge; (4) β-sponge can be eliminated entirely by preventing the top of the coal charge from carbonising and thus leaving a uniformly free passage for gases and vapours to leave the charge; (5) this can be effected by covering the top of the charge with a layer of inert material such as coke breeze; and (6) when the charge is covered with an inert material, a greater amount of volatile matter is evolved as such, without decomposition, so that an increase in by-product recovery is to be expected.

Producer Gas and its Components. M. W. Thring. (Fuel in Science and Practice, 1941, vol. 20, Apr.–May, pp. 64–69). The author points out the difficulties in assessing the usefulness of producer gas from gas analysis and calorific value determinations. This usefulness depends on a combination of three factors, and only by the separate assessment of the three factors can gases obtained under different conditions be compared. In this paper a method of calculating the individual contributions to the calorific value of producer gas of volatile matter, steam and carbon monoxide is applied to a number of gases, and general conclusions are drawn showing the effect of steam addition and of fuel reactivity.

Gas-Producer Plant and Practice. L. Bailly. (Midland Metallurgical Societies: Iron and Coal Trades Review, 1941, vol. 142, June 20, pp. 679–680). The author discusses gas-producer design, factors affecting the rate of gasification, methods of introducing fuel into the producer and the cleaning of the gas. He also makes some recommendations as to the selection of suitable producers for specific purposes.

Increasing Production and Reducing Fuel Consumption in the Production of Producer Gas from Brown-Coal Briquettes. H. Becker and F. Buntenbach. (Stahl und Eisen, 1941, vol. 61, May 1, pp. 441–451). The authors describe the process of producer-gas production from brown coal, giving particulars of some German producers, discussing the disadvantages of some processes and showing how production can be increased by blowing extra air in at the sides of the producer, using oxygen-enriched blast and by superheating the blast.

PRODUCTION OF IRON

Design Modifications in the First Russian Standard Blast Furnace.
(Iron and Coal Trades Review, 1941, vol. 142, June 13, p. 663;
Foundry Trade Journal, 1941, vol. 64, June 26, p. 428). Metal-
lurgical plant in the U.S.S.R. is eventually to conform to the
minimum number of standard designs. In accordance with this
policy a standard blast-furnace has been undergoing extensive
tests under normal service conditions. The present article contains
information from a paper by Kaisstro and Prudnikow on the results
of campaigns with standard furnaces Nos. 1 and 2 at the Woro-
schilow works. These furnaces have been producing an average
of 700 and 800 tons of iron per day respectively. Certain altera-
tions in the lines of the furnaces were decided upon and a description
of these is given together with a diagram.

The Smelting of Ores Rich in Silica under Highly Acid Conditions.
M. Paschke and P. Hahnel. (Stahl und Eisen, 1941, vol. 61, Apr.
17, pp. 385–392; Apr. 24, pp. 417–420). The authors give a
detailed account of a number of full-scale tests on the smelting of
low-grade silica-rich ores with the object of determining the factors
leading to the highest efficiency in the acid-smelting process. It is
shown that the highly-acid smelting with a lime/silica ratio of 0·3
to 0·4 with the furnace charges described in this investigation
brings about a 35% reduction in the coke consumption as compared
with the usual basic smelting. The process described is carried
out in two stages. The product of the first is an iron so high in
sulphur that even desulphurising it with soda ash at the taphole does
not make it suitable for refining in the steel furnaces. The second
stage is that of desulphurising it by a basic process in a second
blast-furnace into which it is charged either in the solid state, or,
if the two furnaces are close together, in the liquid state by a
special runner from the taphole of one furnace to the hearth of the
second furnace in which it is treated under a basic slag. A portion
of the soda-slag obtained is used in the charge of the acid
blast-furnace, where its high alkali content lowers the melting point
of the highly acid slag and thus contributes materially to the work-
ing of the furnace. The acid slag is very suitable for working up
into road-making material as well as for casting into paving-stones.
The economy of the acid-smelting process depends on the physical
properties and chemical composition of the available ores; to
ensure its success the following conditions must be fulfilled : (a) The
proportions in which the ores are mixed must be carefully selected;
(b) the blast and the gas distribution inside the furnace must be
good ; and (c) the furnace must be driven at a high temperature.

The Production of High-Grade Pig Irons in the South of the U.S.S.R. B. Koval. (Stal, 1940, No. 2, pp. 1–8). (In Russian). High-grade low-sulphur and phosphorus pig irons had been produced in the U.S.S.R. only in the Ural region from charcoal and the high-grade Bakal ores. The present investigation at the Almaznyan Works in the South of Russia was concerned with the possibility of producing a similar grade of pig iron from Krivorog ores and low-sulphur coke. The conditions, as regards composition, to which the raw materials had to conform are described and their other characteristics are also dealt with. The phosphorus content of the ore was, on the average, about 0·015%, which is satisfactory. The sulphur content of the coke, which averaged 0·95%, was 0·15% too high, and the ash content (8–9%) also tended to be high. Green slag (from ferro-manganese production) was used as a source of manganese in place of ferro-manganese which had too high a phosphorus content. A method for the production of low-phosphorus manganese is suggested. Details of the No. 2 blast-furnace used for the investigation are given. The first attempts to produce a high-grade pig iron (to a specified composition of silicon 0·75–1·50%, manganese 1·00–2·50%, phosphorus 0·035% max., and sulphur 0·015% max.) using a lime-base slag were unsatisfactory owing to the erratic operation of the furnace. An increase in the basicity of the slag to reduce the sulphur in the metal increased the silicon content. Good results were obtained when the fusion temperatures of the slags were reduced by the addition of a dolomite-limestone mixture to give an MgO content of 5–6% in the slag; the other constituents were CaO 48–50% and SiO_2 32–34%. Data characterising the running of the furnace are given and certain points which could be improved are mentioned. The pig irons obtained conformed to the composition specified above, although the manganese content tended to approach the upper limit. Samples of the pig iron obtained were compared with samples of charcoal pig iron and were found to be equal and in some cases even slightly superior as regards the non-metallic inclusions and the oxygen content. The structures of both types of iron were similar, and repeated remelting had a similar effect in both cases. The mechanical properties were about equal allowing for slight differences in chemical composition.

The Production of High-Grade Pig Iron from Krivorog Ore and Donetz Coke. I. Gokhman. (Stal, 1940, No. 2, pp. 8–10). (In Russian). The raw materials available in southern U.S.S.R. for the production of high-grade (low-phosphorus, low-sulphur) pig iron are considered from the point of view of their phosphorus content, and a phosphorus "balance sheet" showing the contributions of the various constituents of the burden is drawn up. Conditions for the successful production of pig iron of the required purity and the encouraging experiments in this direction at the Almaznyan Works are mentioned. (*See* preceding abstract).

The Desulphurisation of Basic Bessemer Pig Iron. W. Eichholz and G. Behrendt. (Stahl und Eisen, 1940, vol. 60, Aug. 1, pp. 677–683). The authors discuss the results of numerous small-scale and full-scale tests of the factors influencing the desulphurisation of basic pig iron. It is shown that the physical characteristics of desulphurisation are often of greater significance than the chemical reactions. The results of numerous full-scale tests using soda ash alone and soda-limestone mixtures proved that the most efficient desulphurisation was achieved with soda ash and limestone mixed in the proportion of 4 to 5 parts of the former to 3 of the latter, for a great saving in the quantity required was obtained with such a mixture. With this process the sulphur content of the iron on tapping should not exceed about 0·20%. Experiments with the double-carbonate $Na_2Ca(CO_3)_2$, contrary to expectation, did not produce such good results as those obtained with either soda ash alone or soda-limestone mixtures. Desulphurising after the mixer with soda ash alone was more efficient than with soda ash plus limestone ; the quantity of soda ash required was only about 50% greater in this case than when desulphurising at the blast-furnace taphole. With solid soda ash the sulphur in the iron leaving the mixer can be reduced from 0·25% down to 0·06% in one stage, and a soda slag is produced containing less than 1% of lime, about 35% of alkalies and 0·7% of granulated metal. If the sulphur content is much over 0·3%, another method of desulphurising is to charge the iron into a Stürzelberg rotary furnace and add lime. In this way the sulphur can be reduced at a rate of 0·35% per hr. with additions of 5–10% of lime and by an increase of 2–3% in the addition of carbon in the form of small coal or coke breeze in order to maintain sufficiently reducing conditions. Experiments on the desulphurisation of iron in a rotary kiln heated with pulverised coal are still continuing, but it has been found that the process can be accelerated by teeming the iron from the rotary furnace when the sulphur has been reduced to 0·3–0·2%, and finally desulphurising with soda ash. Tests were also made with the process of Bading and Krus in which air carrying finely ground lime was blown into molten iron ; in this case, after blowing for 45 sec., the sulphur was reduced from 0·120% to 0·065% and the silicon from 0·47% to 0·40% ; the manganese content remained unaltered. The last method of desulphurising dealt with was that of treating high-silicon high-sulphur iron with manganese oxides ; in this case the sulphur content was lowered at rates as high as 0·4% per hr.

Factors Affecting the Production of Blast-Furnace Gas. J. S. Fulton. (Iron and Steel Engineer, 1941, vol. 16, Apr., pp. 41–47). In this mathematical treatise the author discusses the relation between the amounts of carbon, oxygen and hydrogen entering a blast-furnace and the composition of the gases leaving the top.

Present-Day Wrought-Iron Production Practice. M. M. Karnaykhov. (Metallurg, 1940, No. 2, pp. 16–22). (In Russian).

After brief reference to earlier developments in the production and status of wrought iron, the Aston process is described. The author goes on to deal with the outstanding features of an attempt to reproduce experimentally the Aston process at a Soviet works. Although the first experiment was unsuccessful, valuable experience was gained from which conclusions were drawn regarding the method of preparation and the composition of the slag, and the behaviour of impurities, in particular nickel and chromium. In subsequent experiments lumps of 100–300 kg. of wrought iron were obtained. Difficulties encountered in forging these lumps are described. Some rolled wrought-iron bars were obtained and their mechanical properties were determined. They proved to be satisfactory.

The Production of Ferro-Aluminium. L. O. Sokolovskiy. (Metallurg, 1940, No. 1, pp. 55–57). (In Russian). The author describes experience gained in the production on a comparatively small scale of approximately 50/50 ferro-aluminium. The material had subsequently to be crushed, as it was intended for the preparation of a calorising mixture. The methods used were : (a) The addition of iron to molten aluminium in an acid crucible ; and (b) the mixing of the two metals after melting them separately.

Electrothermal Ferro-Aluminium. M. S. Maksimenko. (Metallurg, 1940, No. 1, pp. 57–58). (In Russian). The author briefly discusses the possibility of producing ferro-aluminium in a Miguet furnace having regard to its satisfactory use for the direct production of silico-aluminium. A high-grade bauxite should be used. The charge should be made up with peat coke, which has been found excellent for the reduction of aluminium oxides. The constituents should be crushed, mixed and briquetted. The iron should be used in the form of finely crushed swarf. In connection with the use of the ferro-aluminium in calorising mixtures, the author considers the means of limiting the impurities to the required maximum values, namely, carbon 0·2% and silicon 1%. The effect of titanium which may be introduced from the bauxite is uncertain. Even if natural corundum (92% Al_2O_3) should have to be put in partly or wholly in place of bauxite to keep down impurities, the author considers that the product would be cheaper than that obtained by alloying iron and aluminium.

The Use of Cast Iron in Building. S. B. Hamilton. (Newcomen Society : Engineering, 1941, vol. 151, May 23, p. 406 ; May 30, p. 425 ; June 6, pp. 447–448). The author reviews the history of the use of cast iron in building. He refers to the introduction by John Smeaton, about 1755, of cast-iron windshafts and gearwheels for windmills, and calls the 1755–1830 period the tentative period. This was followed by the extensive application of cast iron for textile-mill buildings and other purposes until about 1860, after which a decline, due to the increasing use of steel, set in.

Some Examples of the Amplification of Book-Keeping and Accounting Principles in the Iron-Producing Industry. F. Blom

and L. Kluitmann. (Stahl und Eisen, 1940, vol. 60, Aug. 8, pp. 700–706). The authors describe and give examples of a system of book-keeping suitable for a co-ordinated iron and steel works which operates either as a separate concern or as one of a group of associated companies.

FOUNDRY PRACTICE

Cupola Tapholes. J. Timbrell. (Foundry Trade Journal, 1941, vol. 64, June 5, p. 377). The author describes with diagrams a method of moulding a taphole brick, and of making and ramming plugs for a cupola melting 3–3½ tons per hr.

Notes on the Clay Bonding of Molding Sands. H. L. Daasch. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 113–139). The author discusses factors influencing the bonding of moulding sands. He presents and considers the results of numerous tests which show how the green compressive strength of mixtures of sand with 4% and 8% of bentonite are affected by the amount of water added during the " mulling " of the mixture, and by the heat of wetting, which is the phenomenon of heat evolution during the wetting of a fine powder. It is shown that the strength of heated bentonite-sand mixtures is related to the heat of wetting, which has been found to reach a maximum of 13 cal. per g. of bentonite when the ratio of the water added during " mulling " to the clay content was slightly greater than unity. The strength of the bentonite-sand mixture increases with the heat of wetting.

The Relationship Between the Physical and Mineralogical Characteristics of Bonding Clays. R. E. Grim and R. A. Rowland. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 211–223). The authors determined the green compression strength of mixtures of 8% clay and 92% sand, using fourteen clays of widely different composition. Their study of the relation between the type of clay and the bonding strength indicated that clays composed of montmorillonite had the greatest green compression strength. Clays composed of kaolinite and illite have a lower bonding strength, whilst if a small amount of montmorillonite is present in a mixture of kaolinite and illite, the bonding strength is very greatly increased.

Flowability of Molding Sands. P. E. Kyle. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 175–189). The author describes the hardness-differential method and the sand-movement method of measuring the flowability of moulding sands, and discusses the results obtained with these tests on

some New Jersey moulding sands. In the former method a cylindrical mould 2 in. in dia. is filled with sand, and a 14-lb. weight is dropped on it from a height of $\frac{1}{4}$ in.; hardness readings are then taken at the top and bottom of the specimen; the procedure is repeated on new specimens rammed more severely by increasing the number of blows up to 16. The second method is that suggested by Dietert and Valtier, and it involves the measurement of the movement of the sand in a standard American Foundrymen's Association test specimen in the specimen tube after an initial ramming.

Composite Molding in a Malleable Foundry. S. W. Healy. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 72–83). The author describes the procedure adopted at an American foundry for preparing moulds for malleable iron castings for the automobile industry. The principle of composite moulding, *i.e.*, the moulding of a variety of dissimilar castings in one flask, is that which has been successfully applied at this foundry. Several examples of composite moulds are illustrated and the practical advantages of this technique are explained.

Steel Castings Resist Heat and Corrosion. P. Dwyer. (Foundry, 1940, vol. 68, Dec., pp. 40–42, 104–107). The author describes the plant and layout at an American foundry manufacturing over 9000 tons of heat- and corrosion-resisting chromium-nickel steel castings per annum.

New Roll Shop in Full Production. (Iron Age, 1941, vol. 147, Jan. 30, pp. 46–47). A brief illustrated description is given of the foundry and machine shop of an Ohio company manufacturing cast steel rolling-mill rolls up to 6 ft. in barrel length and up to 5 ft. in dia. Most of the rolls are cast hollow with a 6-in. or 8-in. hole through the centre.

Concerning Scrap Losses. R. F. Coates. (Foundry Trade Journal, 1941, vol. 64, June 5, p. 373). The author discusses a foundry supervision scheme for determining the responsibility for the production of wasters, and gives details of the financial loss incurred by having to make a second 5-cwt. casting to replace a faulty one.

Casting Defects Common to Automotive Gray Iron—Their Identification, Probable Cause and Control. W. B. McFerrin. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 1–29). The author classifies and defines a number of different kinds of defects which occur in grey-iron castings for the automobile industry, gives the probable cause of each and suggests methods of preventing their occurrence.

PRODUCTION OF STEEL

Sharon Steel Corporation. T. J. Ess. (Iron and Steel Engineer, 1941, vol. 18, Apr., pp. 61–71). The author gives a detailed and illustrated description of the blast-furnace, steel-furnace and rolling-mill plant at the works of the Sharon Steel Corporation at Lowellville, Ohio, and at Sharon, Pennsylvania.

Steelmaking. H. R. Dalziel. (Metals Treatment Society of New South Wales: Australasian Engineer, 1941, vol. 41, Apr. 7, pp. 10–12, 34–36). After a brief review of the early history of iron and steelmaking, the author describes in detail the Bessemer, basic open-hearth and duplex processes of producing steel.

Mild Steel—Its Value in Modern Industry. H. A. Dickie. (Metal Treatment, 1941, vol. 7, Spring Issue, pp. 19–24). The author points out that, in spite of the tremendous growth in the use of alloy steels, the range of application of mild steel and its important place in industrial production remain comparatively unaffected. He discusses the degrees of purity of steel manufactured by the open-hearth and Bessemer processes, and refers to the weldability and deep-drawing properties of basic Bessemer steel. In conclusion he gives examples of the extent to which the properties of mild steel can be modified by appropriate methods of manipulation and treatment, which show that in certain forms it is definitely a substitute for, or even preferable to, alloy steels where high yield point or elastic limit is required.

Factors of Open-Hearth Design and Practice. W. C. Buell, jun. (Iron and Steel Engineer, 1941, vol. 18, Mar., pp. 28–35). The author presents data relating to modern American basic open-hearth practice which have been obtained in answer to a questionnaire sent to thirty-five important producers, and draws some general conclusions from this information. These conclusions are : (1) The optimum furnace capacity for satisfactory metal quality and economical maintenance is 150–175 tons ; (2) the depth of the bath of metal should be 30 in. max. for furnaces of 125–200 tons, and about 24–26 in. for those under 125 tons ; (3) the furnaces in a melting shop more than 12 years old cannot be redesigned or rebuilt to incorporate the economies found in most of the new shops constructed within that period ; (4) for the highest efficiency in handling materials the optimum number of furnaces under heat at the same time is six or seven ; and (5) the elimination of excess silicon is one of the most costly items of the furnace phase of steelmaking. The author also develops and explains the use of a simple formula for expressing the tons of steel " P " made per hour per 1000 cu. ft. of metal in the bath ; he finds that P (in

short tons of 2000 lb.) is equal to 15 divided by the duration of the heat in hours.

The Production of Mild Steel in the Acid Open-Hearth Furnace with Special Reference to the Melting Practice. F. Eisermann. (Stahl und Eisen, 1940, vol. 60, July 18, pp. 629–633). The author describes a method of working an acid open-hearth furnace so as to produce good-quality mild steel. He explains the theory of the effect of the manganese in the charge on the metallurgical process, the working of the slag and the reactions with the bottom of the hearth, and discusses how the reduction of the silica affects the cleanliness of the molten steel.

On the Kinetics of the Reactions in the Production of Steel. P. Ya. Ageev. (Metallurg, 1940, No. 2, pp. 3–15). (In Russian). The author points out that Schenck's formula for the rate of oxidation of carbon according to the equation $FeO + C \rightleftharpoons CO + Fe$ in open-hearth and electric furnaces is not in accordance with the true state of affairs and does not explain some results actually observed. It is suggested that the methods of chemical dynamics (the exponential rate of reaction involving the idea of reaction only between activated molecules) should be applied to reactions occurring in the steel-melting process. It is shown how the equations derived will explain such observed facts as the differences in the rates of carbon removal from melts with originally equal carbon and oxygen contents and the consistently slightly higher nitrogen content of electric-furnace as compared with open-hearth steel. The mechanism of the activation of molecules is considered. Since the activation of molecules leads to more rapid reaction and the more rapid completion of the processes involved in the production of steel, it would appear that the electric-arc furnace with its enhanced activating conditions is to be favoured. Attempts to slow down rates of reaction in arc furnaces to the level of those in open-hearth furnaces are misguided.

Economics of the Electric Furnace for Steel Making. H. E. Phelps. (Iron and Steel Engineer, 1941, vol. 18, Apr., pp. 53–57). After giving a brief description of a 50-ton, three-phase, direct-arc electric furnace at a steelworks in Detroit, the author describes the melting practice in detail. To illustrate the great flexibility of such a furnace he reproduces the logs of several heats for different kinds of steel. In conclusion some cost data relating to electric furnace practice are given.

REHEATING FURNACES

Effects of Soaking-Pit Operation upon Steel Conditioning. C. L. Labeka. (Iron and Steel Engineer, 1941, vol. 18, Apr., pp. 25–32). The author points out that the condition of a steel ingot before it

is charged into the soaking pit has a great influence upon its surface quality after it has been rolled to a semi-finished product. He discusses briefly some factors which can be controlled in the open-hearth shop, and, at greater length, the importance of properly controlled soaking-pit practice in reducing the frequency of surface defects in rolled products. It is particularly beneficial to have the ingot-stripping bay close to the soaking pits and to avoid delays between stripping and charging into the soaking pits. Some details are given of a recently installed block of six automatically controlled soaking pits at a Pittsburgh works which are giving very satisfactory service.

Recommendations for the Construction of Furnaces. T. Stassinet. (Stahl und Eisen, 1940, vol. 60, Sept. 12, pp. 809–815). The author discusses the design and construction of soaking pits and reheating furnaces. He shows first how the choice of lining is influenced by the working temperature, the mechanical stresses on the hearth and the amount of scale and slag. When there is much scale the hearth usually has an acid lining and the slag is fluid, whilst with a basic lining the slag is usually dry. The advantages of acid and basic linings are compared and constructional details are given. It is shown that a more even heat distribution is obtained with suspended roofs, whilst the solid arch roof is more easily insulated and is more gas-tight. Some examples of pusher and roller-hearth furnaces are described and methods of preventing air from entering the furnace are discussed. Some batch furnaces are constructed with skids or water-cooled channels along the hearth to facilitate the removal of the billets, but this water-cooling may remove up to 10% of the furnace heat. Constructional details of these skids and channels are also given.

FORGING, STAMPING AND DRAWING

Development in Forging Practice. J. L. Young and J. J. Andra. (Iron and Steel Engineer, 1941, vol. 18, Mar., pp. 41–48). The authors review the history of the development of the art and science of forging and pressing from the Middle Ages up to the present time, concluding with a brief description of a hydraulic machine for piercing shell billets.

Tin Hats Require Many Operations. (Iron Age, 1941, vol. 147, Apr. 24, p. 49). Brief details are given of the many operations necessary in the manufacture of steel helmets.

Cold Pressing. K. Schimz. (Stahl und Eisen, 1940, vol. 60, July 25, pp. 649–655). The author describes various types of cold-pressing machines and the heat treatment and desirable pro-

perties of steel suitable for cold pressing. The paper forms a review of modern American practice, as the author makes several references to recent American publications on cold pressing.

Flexible Metal Tubing. R. J. Metzler. (Iron Age, 1941, vol. 147, Apr. 24, pp. 46–49). The author gives a description, with numerous illustrations, of the processes of cold-drawing, annealing and forming flexible corrugated seamless tubing which can be made of stainless steel, low-carbon steel and certain non-ferrous alloys.

Reduction and Cone Angle of Drawing Dies. P. Grodzinski. (Wire Industry, 1941, vol. 8, May, pp. 235–239). The author develops a single equation for the profile of wire-drawing dies which combines the three following factors : (a) The cone angle of the drawing duct ; (b) the length of the cone in contact with the wire ; and (c) the amount by which the diameter of the wire is reduced.

ROLLING-MILL PRACTICE

Composition Roll Neck Bearings. H. R. Gilchrist. (Iron and Steel Engineer, 1941, vol. 18, Mar., pp. 19–25). The author describes some methods of improving the service life of composition bearings for roll necks. Smoothness of the journal is essential, and lubricating water must be treated with lime if there is any acid in it. The use of guards to keep out scale and grit is advocated and, in conclusion, the results of some wear tests using a Timken lubricant tester to test bearings of different compositions are presented.

Recent Developments in Synthetic-Resin Roll Neck Bearings. H. P. Lemm. (Stahl und Eisen, 1941, vol. 61, May 22, pp. 516–520). The author describes and illustrates some recently developed types of synthetic-resin bearings for roll necks. The use of synthetic-resin collars which press against the ends of the barrel, and means of protecting these collars from scale and dirt, are discussed.

The Conversion of a Light–Medium Bar Mill. E. Wolff. (Stahl und Eisen, 1940, vol. 60, Aug. 8, pp. 697–700). After a brief description of a German bar mill which commenced operations in 1885 and was extended in 1907, the author gives details and illustrations of the reorganisation of the mill with modern machinery which was undertaken in 1939.

Improving the Quality of Hot Rolled Strip. P. J. McKimm. (Steel, 1941, vol. 108, Apr. 28, pp. 74–79 ; May 5, pp. 66–74). The author points out the importance of the correct soaking-pit and reheating-furnace heating for slabs which are to be hot-rolled into strip. He describes and illustrates with micrographs various types of cracks and scale-marks which result from uneven heating or

from having an unsuitable furnace atmosphere in the soaking pit. The relative merits of steel and of chilled cast-iron rolls for the roughing stand are considered, and it is stated that the work done with the former between dressings is frequently three times that done by the latter. In conclusion the importance of making the finishing passes at the correct temperature in order to avoid grain growth by stressing at too high a temperature is pointed out.

Problems in Stainless Steel Production. H. A. Grove. (Iron and Steel Engineer, 1940, vol. 17, Nov., pp. 24–28). The author discusses some of the difficulties encountered in the rolling of stainless-steel strip with particular reference to the need for grinding and annealing between various stages of the rolling, as well as to the sensitivity of this steel to work-hardening.

Hot Strip Coilers and their Drives. R. A. Gender. (Iron and Steel Engineer, 1941, vol. 18, Apr., pp. 34–39). The author describes and illustrates various types of coilers and coiler drives used at modern American mills rolling narrow and wide steel strip at speeds up to 4000 ft. per min.

Power Consumption of Hot-Strip Mills. W. M. Ballenger and L. R. Rhea. (Iron and Steel Engineer, 1941, vol. 18, Mar., pp. 54–62). The authors present data relating to the calculation of the power required to drive modern high-speed continuous hot-strip mills and make some suggestions as to how economies might be effected.

The Steel Mill's First Ignitron Substation. R. R. Longwell. (Steel, 1941, vol. 108, Apr. 21, pp. 72–75, 104). The author discusses the considerations which led to the replacement at an American rolling mill of a 1000-kW. motor-generator sub-station and all its auxiliary equipment by a 1000-kW., 250 V. D.C. Ignitron rectifier with voltage regulating and control equipment. The generator and its equipment had been housed in an old building, and, as the atmospheric conditions were very severe, extensive building alterations and expensive air-conditioning plant would have been necessary. The water-cooling system for the Ignitron unit eliminated the problem of air-conditioning. The new unit surpasses rotating equipment by its ability to take up to 300% over-loads for considerable periods of time without stress or damage. The control scheme is fully automatic ; the rectifier is started and stopped from a remote mill-power control point by the operation of a hand-control switch, the switch setting in motion a master relay in the sub-station. It is claimed that this is the first steel rolling-mill to be controlled by an Ignitron unit.

Rational Shape and Size of the Supporting Guides in a Disc-Type Piercing-Mill. S. I. Borisov. (Metallurg, 1940, No. 2, pp. 38–46). (In Russian). Mathematical formulæ are derived which enable an improved type of supporting guides for a piercing-mill to be designed. The new design is claimed to have a number of advantages over the old type with regard to wear and ease of adjustment.

The Direct Rolling of Liquid Steel. G. Naeser. (Stahl und Eisen, 1941, vol. 61, Apr. 24, pp. 409–416). After a brief discussion of the advantages of a satisfactory process for the continuous casting of steel, the author reviews some of the many attempts which have been made to solve this question from Bessemer's proposal in 1857 up to the present time. He gives brief descriptions and schematic diagrams of several processes (including some for copper and aluminium), concluding with recent attempts by Hazelett. In the Hazelett method the molten steel is poured on to the outer surface of a broad steel cylinder of very large diameter (up to 6 m.); this ring is supported and revolved by a roller turning inside it. The molten steel is carried a short distance to a roller revolving above the ring, which rolls the almost solidified steel into a thin plate or strip. From the latest information available, steel strip up to 6·35 mm. thick has been satisfactorily rolled by this process at a speed of 150 m. per min.

Symposium on Equipment for Mill Crane Bridge Drives. (Iron and Steel Engineer, 1940, vol. 17, Nov., pp. 34–62). The Association of Iron and Steel Engineers decided that the 1929 Standard Crane Specifications should be revised and brought up to date, and a committee was appointed to do this work. The committee was expanded to include representatives of the crane manufacturers. It was decided to hold a symposium in 1940 on drives for rolling-mill bridge cranes, and the papers presented are reproduced in this article. In his introduction F. W. Cramer outlined some of the problems concerning crane-bridge drives. These problems relate to speed, types of drive, bearings and friction, rail stops, power requirements, and braking. The following authors contributed to the symposium : R. J. Harry, H. W. Ball, W. C. Heinle, C. Brongersma, E. C. Rice, R. J. Wadd, G. A. Caldwell, J. A. Jackson, J. R. Lewis, P. B. Harwood, R. L. Puette, H. L. Wilcox and J. C. Cox.

PYROMETRY

The Science of Automatic Temperature Control. C. L. Saunders. Industrial Heating, 1941, vol. 8, Feb., pp. 150–156 ; Mar., pp. 256–260). The author discusses the principles applied in the automatic temperature control of batch and continuous furnaces. He deals first with the factors influencing the selection of an automatic fuel-control valve for batch heat-treatment furnaces, and then considers how the position of the temperature-sensitive element affects the time lag between changes in the conditions of the fuel and/or air supply and the operation of the control valve.

Furnace Temperature Measurements and Their Interpretation.
H. Kreisinger, B. J. Cross and E. H. Kennedy. (Combustion, 1941, vol. 12, Mar., pp. 37–42). The authors compare the advantages and limitations of exposed thermocouples with those of the shielded aspirating type for measuring the temperatures of the products of combustion in furnaces fired with pulverised coal. They also describe how they are calibrated and how the metals forming the hot junction are tested for contamination with oxides. Some details are also given of a water-cooled brass mounting suitable for thermocouples for these furnaces.

HEAT TREATMENT

Flame Hardening with City Gas. J. M. Krappe. (Iron Age, 1941, vol. 147, Apr. 10, pp. 47–50; Apr. 17, pp. 28–31). The author presents data on the types of flame and the heat produced from different types of burners using mixtures of air and natural gas. He finds that such a mixture could be satisfactorily applied for the flame-hardening of steels containing up to 0·7% of carbon. In the second part of his paper he discusses the consumption of natural gas, oxygen and air when using burners of different design.

Design of Burner Tip for Flame Hardening Camshafts. P. B. Terhorst. (Iron Age, 1941, vol. 147, Apr. 24, pp. 60–62). The author presents diagrams and a detailed description of a mixing head and burner which enabled a mixture of oxygen, air and town gas to be used for the flame-hardening of camshaft surfaces. This design replaced the much more expensive water-cooled oxy-acetylene equipment.

The Metallurgy of Induction Hardening. W. E. Benninghof and H. B. Osborn, jun. (Steel, 1941, vol. 108, May 12, pp. 96–98). The authors explain the theory of the heating of metal surfaces by high-frequency induction and the many advantages of applying this process for the hardening of steel parts. A vertical unit and a tunnel-type induction hardening line for the hardening of crankshafts are illustrated.

Construction of Heating Coils for Induction Surface Hardening. G. Babat. (Heat Treating and Forging, 1941, vol. 27, Jan., pp. 39–40; Feb., pp. 89–92; Mar., pp. 137–139; Apr., pp. 192–194). The author considers the characteristics of the coils used for heating steel parts of various shapes in the induction hardening process, and gives many examples of the design of the coils required for heating solid and hollow bars of different shape.

Induction Heating with Electron Tubes. D. B. Clark. (Steel, 1941, vol. 108, May 12, pp. 84–87). In using motor-generator sets

as a source of high-frequency current for metallurgical purpose there is always the drawback that the frequency of the output cannot conveniently be changed. In the present paper the author gives brief particulars of an electron-tube or valve high-frequency converter with an output of 250 kVA., with which it is possible to maintain the load and change the frequency over a very wide range. Converters of this type are made in units covering an output range of 30–400 kVA., and these are being increasingly used in the United States for the control of induction heat-treatment equipment.

The Present Position of the Induction Method of Surface Hardening (Method of the Laboratory of Prof. V. P. Vologdin) and Conditions for its Future Development. V. P. Vologdin. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 37–42). (In Russian). The author and V. N. Romanov claim priority for the invention of the electrical induction method of surface hardening. (Russian patent claims date back to 1935). The method has since been extensively developed, both on the theoretical and practical sides, in the author's laboratory at the Leningrad Electrotechnical Institute. The temperature distribution in the metal, and operating conditions have been fully worked out, and graphs have been obtained correlating frequency and depth of quenched layer. Types of rigid inductors for commercial use have been developed for both round and flat parts. The efficiency of inductors for the latter has been increased considerably by the use of an iron magnetic circuit. A water-cooled iron magnetic circuit is also used in the transformer. Finally, a completely automatic unit has been constructed which is capable of hardening a crankshaft in 2 min. 15 sec. In conclusion, the author discusses the availability in the U.S.S.R. of suitable types of motor and valve high-frequency generators and of condensers. The conclusion is that the induction method of hardening, backed by the considerable experience available, is ready for wide industrial application.

Continuous-Successive Surface Hardening of Steel by the High-Frequency Induction Method. M. G. Lozinskiy. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 50–60). (In Russian). In the introductory part the author considers the various possibilities of applying the method of high-frequency induction heating to the surface hardening of steel. Theoretical aspects of the process are then dealt with, with special reference to the relation between depth of hardening and frequency and to the process of heating up, which may or may not depend on the conduction of heat into the interior of the metal in accordance with the conditions of treatment selected. Overheating at the surface, time of treatment and power consumption are also considered. The author goes on to describe the continuous-successive surface hardening method, in which the surface and the inductor are given a relative movement. The design and arrangement of the essential parts—the inductor and

quenching sprayer—for the treatment of flat surfaces, and for external and internal cylindrical surfaces are described.

Experience of the Stalin Automobile Works with the Surface Hardening of Crankshafts. A. D. Assonov. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 61–66). (In Russian). The high-frequency induction surface-hardening method developed by Professor Vologdin has been successfully applied to the treatment of crankshafts for both petrol and Diesel engines. Contrary to the equipment used by the Crankshaft Co. of Ohio, and that designed by the Allgemeine Elektricitäts-Gesellschaft, that used in the Stalin works eliminates all movement of the crankshaft between the treatment of each neck. The necessary number of inductors (thirteen) are built into one machine, each inductor consisting of two halves, to permit of the crankshaft being inserted. The operation of the inductors is controlled automatically, and the total time of treatment is 2 min. 30 sec. The conditions of treatment are such that no subsequent tempering is necessary before the final machining. In fact, the surface-hardening treatment is incorporated in the machine-tool line. The grain size of the steel should be 6–7. A surface hardness of Rockwell C-60–C-65 is obtained, the structure near the surface being that of very fine, uniformly distributed martensite. The depth of hardening is 4 mm. Certain aspects of the process, such as overheating, quenching cracks and the effect of time of quenching on the hardness, are referred to. Fatigue tests and service wear tests have demonstrated the excellent properties and behaviour of the surface-hardened crankshafts.

Mechanised Heat Treatment. A. G. Robiette. (Metal Treatment, 1941, vol. 7, Spring Issue, pp. 3–9). The author presents a well-illustrated review of modern electric and gas-fired heat-treatment furnaces. Mechanisation has found its greatest application and its widest field of development in the continuous furnace. The movement need not be " continuous " in an absolute sense, for many furnaces, particularly of the pusher and walking-beam types, are intermittent in operation. An unusual form of furnace is a double-drum recuperative furnace for annealing small pressings and blanks. It consists of two concentric drums fitted with oppositely-handed spirals arranged so that the rotation of the whole unit causes the charge to travel along the inner drum towards the heating chamber ; it then falls into the outer chamber, the spiral of which takes the work back towards the entry end. Since the heating chamber proper is only at one end, the rest of the furnace is an insulated recuperative zone, the transfer of heat from the outgoing to the incoming charge being facilitated by its agitation.

Air Supply to Fuel-Fired Furnaces. O. G. Pamely-Evans. (Metal Treatment, 1941, vol. 7, Spring Issue, pp. 15–16). The author points out that the automatic-control mechanism fitted to

gas-fired heat-treatment furnaces frequently operates in such a way that the ratio of gas pressure to air pressure changes substantially with the opening or closing of the valves. He then describes a simple means of correcting this defect by inserting a butterfly valve in the air main at a convenient point between the air supply and the quantity-control valve; this valve is connected to the control mechanism by a suitable reducing linkage. Opening the control gear thus slightly opens the butterfly valve, increases the pressure head at the back of the quantity-control valve, and so makes good the pressure head which has been lost by conversion into velocity head when the valve was opened.

The Use of Commercial Nitrogen as a Neutral Atmosphere in Heat-Treatment Furnaces. M. P. Braun and A. M. Vlasov. (Metallurg, 1940, No. 2, pp. 47–52). (In Russian). In order to eliminate the numerous defects resulting from the heat-treatment of parts at the Stalingrad Tractor Works, it was decided to use commercial nitrogen obtained as a by-product from the near-by oxygen works. In this paper some experiments with this nitrogen are described. The oxygen (3–6%) in the commercial nitrogen was removed by passing the gas through an electrically heated retort containing carbon. The gas was first dried with charcoal or calcium chloride, and then passed through the retort (kept at a max. temperature of 850–950° C.), which in the first experiments was filled with charcoal. The exit gases were again dried, and then passed over heated copper turnings before being admitted into the heat-treatment furnace. Plain carbon and low-alloy steels were used in the experiments, in which changes of weight were recorded and decarburisation, if any, was determined by the microscopical examination of sections. The surface of the specimens in the first experiments was quite satisfactory after they had been heated for 2 hr. at temperatures of 700–950° C. All the specimens showed losses in weight and were found to have suffered considerable decarburisation. In the second series of experiments decarburisation was prevented by using a mixture of coal and charcoal in the retort. The coal gave rise to methane and hydrocarbons, which effectively prevented decarburisation. The changes in weight of the specimens were negligible and their surface appearance excellent. It is intended to convey the nitrogen from the oxygen works through a pipe-line 2 km. long at a pressure of 6 atm. The costs are expected to be low.

Electric Heating and Electric Quenching. N. V. Geveling. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 43–49). (In Russian). The author discusses the use of an electric current to heat up ingots or billets prior to hot-working or quenching. D.C. or low-frequency A.C. can be used, and the method is much more efficient than ordinary furnace heating. In addition, the rate of heating can be greatly increased, as the heat is generated uniformly throughout the metal. It is, therefore, unnecessary, as in the case

of furnace heating, to limit the rate of heating up in order to avoid temperature gradients and consequent dangerous internal stresses, especially with the low thermal conductivity alloy steels. Direct electric heating can also be used to advantage for the tempering of quenched steel parts. By this method softening of the surface layers can be avoided. In fact, by cooling the surface, *e.g.*, by immersing the part in oil, tempering can be confined to the core— an obvious advantage in the case of tools. Alternatively, parts can be treated to obtain a tempered outer zone and a residual hard quenched core. Investigations have shown that with direct electric heating of heterogeneous metal structures the heat is evolved in the vicinity of the constituents with lower electric conductivity, *i.e.*, just where the heat is required to obtain homogeneity by solution and diffusion. The rapid and localised heating prevents any appreciable grain-growth of the austenite and, even with overheating, a fine martensite structure can be obtained almost instantaneously. In conclusion, electrical surface-hardening methods are mentioned, reference being made to means of avoiding the formation of stresses.

WELDING AND CUTTING

Present-Day Problems in the Welding of Structural Steels. M. Roš. (Swiss Acetylene Association : Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, 1941, Report No. 132). The author reviews the state of the development of the technique of autogenous and electric welding that has been attained in Switzerland. The precautions to be taken in the welding of all kinds of constructional work, including pipe-lines, bridge girders, roof trusses, steel masts, high-pressure vessels, &c., are described. Some of the maximum loads for different welded structures permitted by Swiss regulations are quoted, and recommendations are made for certain modifications to these regulations so as to bring them in line with the progress that has been made in welding technique. Examples of welds, welded structures and tests are shown in 112 photographs and diagrams which accompany the text.

Grain Refinement in the Arc Welding of Heat-Resisting 30%-Chromium Steel. G. M. Tikhodeev and L. E. Fedotov. (Metallurg, 1940, No. 2, pp. 31–37). (In Russian). The welding experiments described by the authors were carried out on as-rolled strips 25×6 mm. in cross-section of heat-resisting steel of the following composition : Carbon 0·12%, manganese 0·27%, silicon 0·93%, chromium 28·0%, nickel 0·31%, phosphorus 0·025%, and sulphur 0·024%. The first welds were made using imported electrodes

with a coating containing CaF_2, $CaCO_3$, ferro-manganese and water-glass. The tensile strength of the welds was low (30–40 kg. per sq. mm.) and they could practically not be bent at all without fracturing. The weld metal was coarse grained. Gas welding gave even worse results, as it caused excessive grain growth in the parent metal adjoining the weld. This effect was absent with arc welds. It was decided to obtain grain refinement in the weld metal by introducing titanium and aluminium from the electrode coating. After numerous tests the following composition was arrived at : Fluorspar 35%, marble 25%, 23%-ferro-titanium 20%, and 49%-ferro-aluminium 20% with a water-glass binder. The metal used for the electrodes contained carbon 0·07%, manganese 0·26%, silicon 0·49%, chromium 34·4%, nickel 0·21%, sulphur 0·03% and phosphorus 0·005%. These electrodes produced a fine-grained weld metal, the tensile strength of the welds increasing 50–60% up to 58 kg. per sq. mm., i.e., up to the tensile strength of the parent metal. The ductility, however, remained low, which is a characteristic of this steel in the cast state. The ductility could be improved by quenching in water from 750° to 800° C. Analyses were made to determine the behaviour of the constituents of the coating during welding. The weld metal was found to contain 0·23% of titanium and 0·12% of aluminium. Both the weld metal and the adjoining parent metal were subjected to microscopic examinations and their structure—notably the presence of an intergranular carbide network in the weld metal—was related to their mechanical properties.

Investigation of the Weldability of Silicon-Chromium-Molybdenum Heat-Resisting Steel. G. M. Tikhodeev and L. N. Solov'eva. (Metallurg, 1940, No. 2, pp. 23–31). (In Russian). The silchrome-molybdenum steel $SKhM6$ used in the welding experiments described by the authors was in the form of 4 mm.-thick sheet and it contained carbon 0·12%, silicon 1·74%, manganese 0·47%, chromium 6·09% and molybdenum 0·29%. The filler materials used were 4 × 4 mm. rods of the same composition as the parent metal and 4 mm.-dia. wires of 18/8 and 25/20 chromium-nickel stainless steels. Gas welds were made with a neutral flame using no flux, whilst for arc welds the wires were covered with flux and connected to the positive terminal. Hardness, bend and tensile tests were made on butt welds, and the microstructure of the weld metal was examined. Steel $SKhM6$ exhibited quench-hardening in regions adjacent to the weld, and this was reflected in the mechanical properties ; this hard zone might lead to fracture near the weld. The best results were obtained by arc welding using 25/20 stainless steel electrodes. It was shown that the effects of quench-hardening could be eliminated by normalising at 750–800° C. This improved the ductility of the welds. Normalising may not be necessary if the welded parts are intended for high-temperature service. In conclusion, some experiments on the corrosion resist-

ance of welded specimens were carried out at a temperature of 700° C. in products of combustion containing sulphur dioxide. The results showed that the corrosion resistance of the welded specimens was equal to that of the unwelded parent metal.

Dilution of Austenitic Welds by Mild Steels and Low Alloys. R. D. Thomas, jun., and K. W. Ostrom. (Welding Journal, 1941, vol. 20, Apr., pp. 185-S–189-S). The authors describe an investigation of the amount of the loss of chromium and gain in carbon in weld metal at different distances from the parent metal when a chromium-nickel electrode is used to weld a carbon-steel plate. In one case pads of weld metal from 19/9 chromium-nickel steel electrodes were built up to a height of $\frac{3}{8}$ in. on a 0·31% carbon steel plate, and a series of steps $\frac{1}{16}$ in. deep were machined off down to $\frac{1}{32}$ in. below the original surface. The cuttings were analysed for carbon and chromium. The results showed that the chromium content was reduced from 18·77% at a height of $\frac{3}{8}$ in. to 11·02% at a depth of $\frac{1}{32}$ in., whilst at the same levels the carbon contents were 0·082% and 0·17%, respectively. Some results of similar tests at different positions across the section of a butt weld in a $\frac{3}{4}$-in. mild steel plate are also recorded.

The Effect of Welding on the Structure of Some Cast and Wrought Steels. A. J. Smith and J. W. Bolton. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 31–65). The authors explain the general principles involved in the alteration of the structure of steel as a consequence of welding, and correlate with these principles the structures developed in certain well-known grades of cast steel when they are welded to common wrought steel. They make use of the results reported in a previous investigation as examples (*see* Journ. I. and S.I., 1940, No. I., p. 200 A). They discuss in particular the factors influencing the grain-coarsening tendency, and show that, under the conditions of their investigation, cast steels have just as good, and in many cases better, weldability than comparable rolled steel.

Design in Hard-Surfacing. M. Riddihough. (Welding Industry, 1941, vol. 9, Apr., pp. 60–62). The author makes recommendations on the design of steel parts which are to be " hard-surfaced " by welding on a layer of a hard alloy. He describes and illustrates the correct design of a number of parts such as corn crushers, teeth for excavator buckets, shear blades, valve seats, shafts and sleeves.

MACHINING

Economics of Cemented Carbides on Variety Production. C. D. Mackinnon. (Machine Shop Magazine, 1941, vol. 2, June, pp. 62–

70). The author discusses the use of tungsten-carbide-tipped tools in a general machine shop where a large variety of work is undertaken. He also describes the operation of brazing carbide tips to high-tensile steel shanks, the grinding and care of these cutting tools, and how broken tips can be salvaged by brazing the broken pieces and regrinding to form a new tool.

The Use of Ultra-High Speeds in the Cutting of Metals. E. P. Nadeinskaya. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 32–36). (In Russian). The author briefly reviews a number of papers on the high-speed cutting of metals which were presented at a meeting of a commission on the cutting of metals of the People's Commissariat for Heavy Machine Construction. In the first paper, Professor Kuznetsov discussed the theoretical aspects of energy consumption in machining and pointed out that, as at higher speeds the metal tended to behave as a brittle body, the energy consumption in machining would decrease owing to the much smaller plastic deformation of the metal. At the same time, friction between tool and metal, and, consequently, the amount of heat generated, would also be reduced. Some experimental results obtained when turning steel at an initial speed of 1500 m. per min. were mentioned and appeared to support the above deductions. Experimental work described by Burshteyn did not bear out the suggestion made by Professor Kuznetsov regarding the small amount of heat generated at high speeds. Actually, high temperatures were reached, and it is suggested that still higher speeds would appear to be necessary to obtain a reduction in the amount of heat evolved. In the next paper Fedorov referred to band and disc saws which are run at high speeds of 50–100 m. per sec. and depend for their action on friction and the melting of the metal being cut. Their efficiency is many times greater than that of any other metal-cutting tool. Reference was also made to grinding-discs. In the paper by Shchelkonogov it was suggested that in cutting at high speeds, the rapid displacement of the metal would lead to the metal heating up in advance of the tool and this would possibly facilitate cutting with an internally water-cooled tool. Some confirmatory preliminary experimental results were mentioned.

CLEANING AND PICKLING OF METALS

Flame-Cleaning of Structural Steel. F. H. Dill. (Welding Journal, 1941, vol. 20, Apr., pp. 231–234). The author describes the process of cleaning steel prior to painting by means of a torch burning acetylene, hydrogen or propane in conjunction with oxygen. Some advantages of the process as compared with sand-blasting

are pointed out, but it is also stated that flame-cleaning is rather expensive and that it is only economically justified on large structures where real savings in subsequent maintenance may result.

An Improved Pickling Process. J. Kronsbein. (Tin and Its Uses, 1941, May, pp. 9–10). The author describes a development of the Bullard-Dunn process of electrolytic pickling. In this process the iron or steel article to be pickled is made the cathode in a hot dilute solution of sulphuric acid containing about 1 g. of tin sulphate per litre. The current density is of the order of 60–80 amp. per sq. ft. The tin ion concentration is so small that no tin is plated on scale, but, as soon as the scale is removed from the surface, a protective film of tin is deposited and there is no further attack by the acid at that point. The tin content of the bath is maintained by having a small percentage of the anodes of pure tin, whilst the majority of the anodes are made of high-silicon iron.

Automatic Equipment for Electrolytic Descaling. S. E. Ryskin. (Vestnik Metallopromyshlennosti, 1940, No. 3, pp. 66–68). (In Russian). The process and equipment which the author describes are used in preference to sandblasting for the removal of scale from carburised parts at the Stalin Automobile Works. The process comprises the following operations : (1) Anodic degreasing in a solution of caustic soda and trisodium phosphate. The time taken is 10–15 min. with a current density of 5 amp. per sq. dm. at a temperature of 80–90° C. (2) Rinsing for 1 min. in water at 50° C. (3) Rinsing for 1 min. in cold water. (4) Cathodic descaling in a solution of sulphuric and hydrochloric acids containing sodium chloride with a current density of 7 amp. per sq. dm. at 6 V. ; the time required is 10–15 min. at a temperature of 60–70° C. A number of lead anodes are used and the descaled surfaces are protected by a deposition of lead. (5) Rinsing for 1 min. in water at 50° C. (6) Rinsing for 1 min. in cold water. (7) The protective lead coating is removed by anodic treatment in alkaline solutions at a temperature of 50–60° C. in 8–10 min. (8) Rinsing for 1 min. in cold water. (9) Rinsing for 1 min. in water at 85–95° C.

The equipment is briefly described. Its output capacity amounts to 2600 sq. dm. per hr.

A Short Research on the Effect of Base Metal Polishing on the Character of Nickel Plate. W. L. Pinner. (Metal Finishing, 1941, vol. 39, Feb., pp. 76–82). The author reports on an investigation of the effect of the size of the grit used for polishing steel on the protective properties of a subsequently applied nickel coating. Groups of specimens of a hot-rolled, heat-treated spring steel, a commercial quality of cold-rolled steel and a special quality of cold-rolled steel were polished with a dry wheel using grain sizes from 90 down to 220, and, after plating in a modified Watts nickel bath, they were subjected to salt-spray tests. It was observed that the grit-size and polishing procedure had a marked effect on the porosity of the nickel coating. The coarser grit-sizes tended

to cause more porous nickel coatings, and the best results were obtained when a 220-size grease-wheel was used for final polishing. The complete elimination of scratches was not necessary as long as the polishing removed the tops of the ridges of the scratches.

COATING OF METALS

Bright Nickel Plating. E. E. Halls. (Metal Treatment, 1941, vol. 7, Spring Issue, pp. 11–14, 9). The author gives a detailed description of the processes of bright nickel plating using organic and cobalt brighteners, and presents the results of accelerated corrosion tests which show the relative protection offered by different thicknesses of bright nickel and ordinary nickel plating.

Wire Production Practice. (Wire Industry, 1941, vol. 8, May, pp. 247, 261). A brief description is given of a continuous process for the bright nickel plating of wire. The Watts bath is usually employed in which the electrolyte is made up of 37 oz. of nickel sulphate, 8 oz. of nickel chloride and 3 oz. of boric acid per gallon. The wire is passed through a tubular nickel anode in the bath, which is kept at a temperature of 110–120° F. The current is passed at the high density of 40 amp. per sq. ft. of wire surface. Some particulars are also given of a photo-electric reflectometer with which the degree of lustre of the coating can be accurately determined.

The Surface Treatment of Steel by Chromium Diffusion. G. Becker, K. Daeves and F. Steinberg. (Stahl und Eisen, 1941, vol. 61, Mar. 20, pp. 289–294). The authors describe the development of a process of diffusing chromium into the surface of steel in order to form a corrosion-resisting surface layer. In the laboratory method a stream of chromium-chloride gas is passed over the steel which is heated in a muffle or retort. At room temperature chromium chloride is a solid salt which absorbs moisture. In order to stabilise it, it has been found possible to impregnate certain ceramic aggregates with the chloride, and on an industrial scale the steel to be treated is packed in this material and heated. An analysis of specimens shows that the chromium penetrates to about 0·15 mm. The chromium content at the surface is about 35%, and it decreases to about 8% at a depth of 0·1 mm. The best results are obtained with low-carbon steel of thin section. If high-carbon heavy-section steel is to be treated it must contain an alloying element which inhibits the resistance of the carbon to the penetration of the chromium. Some examples of the successful chromium cementation of steel tubes, balls and milk cans are described and illustrated.

How to Save Zinc in Hot-Dip Galvanizing. W. G. Imhoff. (Steel, 1941, vol. 108, Mar. 24, pp. 56, 57, 86, 87). The author

makes some practical recommendations for reducing the quantity of zinc which collects in the dross in the hot-dip galvanising process, as well as for recovering the metallic zinc from the dross and skimmings.

Tinplate Manufacture—A Bibliography. V. S. Polansky. (Blast Furnace and Steel Plant, 1941, vol. 29, Feb., pp. 205, 210, 211, 257; Apr., pp. 421–424). A bibliography on the manufacture of tinplate arranged in alphabetical order of authors is presented.

Research Has Provided a Smooth Drive for a Tinning Unit. W. E. Hoare. (Sheet Metal Industries, 1941, vol. 15, May, pp. 623–624). The author has described in a previous paper the characteristics of markings appearing on tinplate at right angles to the direction of movement of the sheet through the tinning unit (*see* Journ. I. and S.I., 1937, No. II., p. 99 P). These markings are known to be caused by vibratory movements which disturb the regular and smooth motion of the rollers of the tinning unit. In the present paper he describes an experimental machine at the laboratories of the Tin Research Institute which was designed to provide a really smooth drive for the grease-pot rollers. This object was achieved in the main by having as many as possible of the components of the drive outside the grease-pot, where operation was not subject to the limitations imposed by conditions inside the pot. (*See also* this Journal, Section I.).

Hot-Tinning of Steel. (Canadian Metals and Metallurgical Industries, 1941, vol. 4, Mar., pp. 50–53). After a general description of the hot-dip process of tinning steel, details are given of the modified processes known as the sal-ammoniac and the grease-tinning process for treating thin steel. A difficulty met with is that of removing the tin-iron compound from the bath, as this is practically insoluble in molten tin at tinning temperatures and, if more than a very small amount is present, it exists in the form of minute solid particles. The method usually employed to remove these compounds is to immerse raw potatoes or pieces of green wood in the bath. This causes a vigorous boiling of the tin, and as the compound particles come to the top, they are caught by the oxide film to form a heavy pasty dross which can easily be skimmed off. Another method is to blow compressed air into the bath, which, in addition to raising the particles by the resulting agitation, also causes particles of tin oxide to form, and as these float to the surface they carry the compound with them. The compressed-air method is more rapid than the potato method.

Protective Films on Tinplate by Chemical Treatment. R. Kerr. (Tin Research Institute, 1941, Publication No. 104). The author describes a process of producing a sulphur-resisting coating on tinplate used for packing foodstuffs. This-paper appeared previously in the Journal of the Society of Chemical Industry, 1940, vol. 59, Dec., pp. 259–265. (*See* Journ. I. and S.I., 1941, No. I., p. 180 A).

Do You Realize the Important Possibilities of Metal Spraying in Repetitive Production Work? W. C. Reid. (Steel, 1941, vol. 108, Apr. 14, pp. 52–53, 87–90). The author points out that metal spraying should receive consideration in the manufacture of new plant, a sphere of application which is at present neglected. He describes the process and equipment used for depositing alloys on cylindrical surfaces in order to provide a hard wear-resisting coating, and gives tables of the cost of spraying stainless steel and a number of non-ferrous metals and alloys.

Stainless Clad Plate. R. E. Kinkead. (Iron and Steel Engineer, 1940, vol. 17, Nov., p. 29). The author briefly describes two methods of producing a composite plate consisting of a carbon-steel base with a stainless-steel coating. One of these is the Union-melt welding process, which has been described previously (*see* Journ. I. and S.I., 1939, No. I., p. 284 A). In the second process the steel plate is covered with a uniform layer of ferro-chromium and nickel shot; this is in turn covered with a layer of furnace slag; electric arcs are then caused to traverse the surface of the plate by moving carbon electrodes above it, and this causes the alloying elements to pass on to the plate under the slag, which excludes the air, thus preventing or reducing the oxidation. Some possible commercial applications of clad plate are discussed.

Clad Metals. (Automobile Engineer, 1941, vol. 31, May, pp. 157–161). Brief descriptions are given of electro-chemical and welding processes for the homogeneous attachment of dissimilar metals over a large surface, a process generally known as cladding. Various combinations of metals, their application and characteristics are discussed, and the correct technique for oxy-acetylene cutting mild steel clad with stainless steel is described.

Modern Processes for Phosphatising Iron and Steel. L. Schuster. (Stahl und Eisen, 1940, vol. 60, Sept. 5, pp. 785–790). After a brief discussion of the theory of phosphatising, the author describes in detail the long-time process, in which a coating is formed in 30–60 min., and the short-time process (*i.e.*, bonderising), in which only a few minutes are required to deposit the coating. The advantages of the latter process are pointed out, with particular reference to the manner in which it facilitates the cold-drawing of iron and steel, for, with phosphatised steel, there is no need for intermediate annealing and pickling when cold-drawing, there is less friction in the dies and the output of the drawing machinery is thus increased.

Observations on Cast-Iron Enamelling. A. Biddulph. (Institute of British Foundrymen and Institute of Vitreous Enamellers : Foundry Trade Journal, 1941, vol. 64, May 1, pp. 301–302 ; June 5, pp. 379–380). The author discusses the design, manufacture, cleaning and enamelling of iron castings. In considering the causes of blistering, it is pointed out that if general blistering over the whole surface of an enamelled casting occurs, the cause is

generally to be found in the enamelling shop, but if, as is more usual, the blistering covers only 5% or less of the surface, the cause can probably be traced to the foundry. Some causes of local blistering of an enamelled casting are discussed in detail, with particular reference to the effect of different sizes of chilled iron shot for shot-blasting, of water and oil in the compressed air, and of the type and manipulation of the nozzle.

Factors Affecting Sagging Tests on Enameling Iron. J. E. Sams, W. McGohan and J. J. Canfield. (Journal of the American Ceramic Society, 1941, vol. 24, Apr., pp. 137–140). The authors report on some laboratory tests in which the effect of such factors as furnace size, temperature, rate of heating, width of sample, and thickness of enamel coating on the results of sagging tests on strips of 20 gauge enamelling iron were investigated. The conclusions reached were as follows : (1) The sagging was practically constant when a coating weight of 18·5—21·5 g. of dry enamel per sq. ft. of surface was used, but the sagging was not constant for samples with a very light coating ; (2) wide samples sagged less than narrow ones ; (3) on increasing the holding time at 1600° F. up to 5 min. the amount of sag increased rapidly ; for holding times of 10 min. and longer the amount of sag increased more slowly and at a constant rate ; (4) at up to about 1550° F. the sagging increased slowly with the temperature, and then began to increase rapidly ; and (5) enamelling iron with 0·017% of carbon sagged much less than steel, and under equivalent conditions the sagging increased with increasing carbon content.

PROPERTIES AND TESTS

A Rational Definition of Yield Strength. W. R. Osgood. (Transactions of the American Society of Mechanical Engineers, 1940, vol. 62, pp. A-61–A-62). In this mathematical treatise the author proposes a definition of yield strength which has the advantage that, for geometrically similar structures of different materials, the loads which produce maximum stresses equal to the yield strength are proportional to the yield strength.

Combined Tension-Torsion Tests on a 0·35 per cent Carbon Steel. E. A. Davis. (Transactions of the American Society of Mechanical Engineers, 1940, vol. 62, pp. 577–584). The author describes the equipment used for carrying out combined tensile and torsion tests, and discusses the results obtained when applying these tests to specimens of 0·35%-carbon steel. As the tests were related to the problem of bolting, the strength of specimens on which circumferential notches were cut was also determined. Curves are pre-

sented which show how the tensile strength is reduced by increasing the torque, as well as the reduction in torsional strength when a tensile load is applied.

The Relationship Between Stress and Strain in the Tensile Impact Test. A. F. C. Brown and N. D. G. Vincent. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 145, pp. 126–134). The authors describe an apparatus devised for measuring the relationship between stress and strain on metallic specimens broken under tensile impact. The stress was measured piezo-electrically and the strain photo-electrically. Five ferrous materials were tested with this machine at rates of extension ranging up to 800 in. per in. per sec., with the following results : (1) With specimens of Best Yorkshire wrought iron there was an increase in tensile strength and a considerable increase in the yield point as the rate of strain was raised ; (2) with normalised medium-carbon steel there was some increase in the yield point ; (3) with low-carbon manganese steel, nickel-chromium steel and a high-carbon, nickel-chromium-molybdenum steel, all oil-hardened and tempered, there was little difference between the impact and static stress-strain diagrams ; and (4) the energy absorbed in fracturing the specimens in the impact tests was only slightly greater than that absorbed in the static tests.

Local Martensite Formation on the Surface of Rails. B. Božić. (Stahl und Eisen, 1940, vol. 60, Aug. 22, pp. 745–746). The author describes the investigation of surface defects in some rails which were laid on a steep incline. An examination of the microstructure revealed that martensite had formed at places where the severe application of the locomotive brakes had caused overheating, with subsequent sudden cooling by the surrounding mass of the rail.

The Action of the Haigh Fatigue Testing Machine. (Engineer, 1941, vol. 171, May 30, pp. 350–351). The design and working principles of the Haigh fatigue-testing machine are explained, and some details are given of an investigation of the reasons for a variation of 3–5% in the calibrations carried out on one of these machines at different dates. This investigation was undertaken by E. Warlow-Davies, who discovered that the immediate error was due to an error in the tachometer which was slowly increasing. This explanation was, however, not in conformity with the generally accepted simple theory of the machine, according to which the calibration should be sensibly independent of the speed. A further investigation in which the wave form of the stress in the test-piece was examined by means of a Lamb roller extensometer is described. This showed that at a stress-cycle frequency of 2330 per min. the shape of the stress curve was practically sinusoidal. At lower frequencies the curve became still better, whilst at higher frequencies it became worse. This distortion was found to be independent of the stress range and dependent only on the frequency. A mathematical study is then presented which indicated that at certain critical frequencies of the stress application, the inevitable

small departures of the electrical input from sinusoidal form may result in a mechanical resonance in the specimen and in the form of the stress cycle being far from sinusoidal. This deduction was proved to be correct by subsequent experiments.

Jominy Test of Meehanite. A. C. Denison. (Iron Age, 1941, vol. 147, Apr. 24, pp. 41–45). The author describes a form of Jominy end-quench hardenability test, and discusses the results obtained with it on specimens of Meehanite metal. (*See* p. 25 A).

Wear of Diesel-Engine Cylinders and Rings. P. S. Lane. (Transactions of the American Society of Mechanical Engineers, 1940, vol. 62, pp. 95–108). The author reviews data on the rates of wear of cylinder liners and piston-rings in medium and heavy Diesel and gas engines. He correlates the results of laboratory wear tests with service experience, and discusses the effects of section size, hardness, composition and structure of piston-rings on the rate of wear.

An X-Ray Examination of Mechanical Wear Products. H. J. Goldschmidt and G. T. Harris. (Journal of Scientific Instruments, 1941, vol. 18, May, pp. 94–97). The authors describe how X-ray methods were used to study the problem of wear or abrasion under unlubricated conditions in air. Powders produced by the abrasion of steels in wear-testing machines were collected and examined, and it was found that these consisted of mixtures of the parent metal (ferrite) and iron oxide. The oxides observed were FeO and Fe_3O_4, never Fe_2O_3. Small amounts of cementite (Fe_3C) were also present in certain cases. The relative amounts of α-iron, FeO and Fe_3O_4 in the powder depended characteristically on the composition of the steel, its phase constitution, and certain experimental factors.

Screw Machine Steels. A. S. Jameson. (Iron Age, 1941, vol. 147, May 1, pp. 31–39). The author explains how the machinability of steel is increased by the addition of sulphur and/or phosphorus, by controlling the microstructure, by cold drawing and by the addition of lead.

New Alloy Steel. H. V. Putnam. (Steel, 1941, vol. 108, Apr. 21, pp. 52–53). The author gives some particulars of a recently developed alloy steel for transformer cores ; it is known as " Hipersil," a name derived from " high-permeability silicon." This steel has a preferred grain orientation in the direction of rolling. It is claimed that its magnetic permeability is one-third higher than that of the usual silicon transformer steel, whilst its cost is about twice that of hot-rolled silicon steel. The size and weight of transformer cores can be reduced if this steel is used, and, in making distribution transformers, less iron, copper and cooling oil are necessary, with the result that an aggregate saving of 20–25% in the weight of a complete transformer is effected.

Relaxation of Metals at High Temperatures. W. E. Trumpler, jun. (Journal of Applied Physics, 1941, vol. 12, Mar., pp. 248–

253). In high-temperature apparatus, parts such as bolts are frequently subjected, not to constant load, but to constant total strain ; creep then acts to elongate the bar and partially to release the load. This phenomenon has become known as relaxation. In the present paper the author describes an automatic relaxation testing machine on which a continuous stress-time curve can be obtained on steel specimens held at any desired temperature below 750° C. The mechanism is sufficiently sensitive for the motor operating the unloading device to be set in motion by a change of strain of approximately 2×10^{-6} in. per in. It was found by tests on bolt material that, as a rule, after one week the stress decreased very slowly ; the duration of a test therefore became about 150 hr. Some examples of the stress-time curves obtained are reproduced and their value to the design engineer is discussed. The machine described has given accurate and consistent results for more than two years, and it is suggested that this form of test may become as standard as a creep test at a great reduction of testing time.

The Effect of Varying the Silicon Content of Cast Iron. F. G. Sefing. (Transactions of the American Foundrymen's Association, 1940, vol. 48, pp. 161–168). The author reports on an investigation undertaken with the object of observing the changes in the properties of test bars of cast iron containing total carbon 2·75%, 3·00%, 3·35% and 3·50% when the silicon content was gradually increased from 1·25% to 2·50%. The following conclusions were drawn from the test results : (1) There is an optimum silicon content for each carbon content at which the hardness values are of the same order for both light and heavy sections ; (2) the tensile strength of an iron containing 3·50% total carbon decreases with increasing carbon content, but when the total carbon falls to 2·75% an increase in the silicon raises the tensile strength ; and (3) the increase in the tensile strength amounts to about 5000 lb. per sq. in. for each 0·25% reduction in the total carbon.

The Use of Copper in Iron and Steel. J. E. Jackson. (American Foundrymen's Association : Steel, 1941, vol. 108, May 19, pp. 76–80). The author discusses the beneficial effects of small additions of copper to steel and to cast iron. Tables and graphs are given showing the increase in tensile and transverse strengths of cupola cast iron and of malleable iron, as well as particulars of the manner in which the copper is added.

The Strength Properties of Heat-Treatable Alloy Steels Containing neither Nickel nor Molybdenum. H. Kiessler. (Stahl und Eisen, 1941, vol. 61, May 22, pp. 509–516). The author discusses the results of numerous tests on specimens of the alloy steels, which do not contain any nickel or molybdenum, proposed by the Verein Deutscher Eisenhüttenleute and referred to in the Fliegwerkstoff-Handbuch. The values obtained for tensile strength, elastic limit, elongation, reduction of area and impact strength showed that in

all cases except one, the proposed manganese-chromium-silicon alloy steels complied with the test specification. The steels with chromium as the principal alloying element had better reduction-on-area and impact-strength properties than those in which manganese was the principal alloying element. The torsional-fatigue strength of some heat-treatable steels containing neither nickel nor molybdenum are also given.

Weldable High-Strength Vanadium-Bearing Structural Steels. H. Cornelius. (Stahl und Eisen, 1940, vol. 60, Aug. 1, pp. 684–687). In Germany there has been a desire to find a suitable substitute for the weldable alloy steel containing chromium 1% and molybdenum 0·20%. In the present paper the author reports on an investigation of the mechanical and welding properties of steels containing carbon 0·25–0·30%, silicon 0·3–0·8%, manganese 0·5–1·6%, vanadium 0·25–0·6% and chromium up to 1%, with the object of finding such a steel which in the form of thin sheet and tube would be easily weldable and which would have a tensile strength of at least 90 kg. per sq. mm. in the heat-treated state. Full details of the analyses, heat treatment and test results are given. From a study of these data the authors recommend a steel containing carbon 0·24–0·30%, manganese 1–1·3%, chromium 0·6–0·9% and vanadium 0·1–0·2%.

High-Strength Weldable Chromium-Manganese Structural Steels. W. Eilender, H. Arend and E. Schmidtmann. (Stahl und Eisen, 1941, vol. 61, Apr. 17, pp. 392–396). The authors describe an investigation the object of which was to develop a chromium manganese steel containing no molybdenum to replace the high-strength weldable steel containing chromium 1% and molybdenum 0·2%. For this purpose a number of steels with carbon 0·12–0·24%, manganese 1·2–1·9% and chromium 0·7–1·1% were prepared in a 100-kg. basic H.F. furnace. The billets from these melts were rolled down to sheets 1 and 1·5 mm. thick. These were heat-treated in various ways and submitted to tensile, shear, deep-drawing and reverse-bend tests, the results of which are given in numerous tables. Butt-welded specimens were also tested for tensile strength, hardness and weldability, and it was shown that in spite of phosphorus and sulphur contents of up to 0·046% and 0·030%, respectively, the chromium-manganese steels passed the Focke-Wulf weldability test satisfactorily. From the results obtained the authors conclude that the chromium-molybdenum steel can be replaced by a steel containing carbon 0·21–0·25%, manganese 1·3–1·5%, phosphorus and sulphur each 0·03% max., and chromium 0·6–0·8%. The increase in the hardness of this steel on welding is very slight. Impact tests at + 20° C. and − 70° C. showed that it had less tendency to cold-brittleness than chromium-molybdenum steel. If a high impact strength and good deep-drawing properties are required, the melting should be controlled so as to produce a fine grain. An addition of 0·25% of vanadium

did not produce any marked improvement in the properties of the chromium-manganese steel.

A Non-Magnetic Structural Steel with 17–18% of Manganese. G. Riedrich. (Stahl und Eisen, 1940, vol. 60, Sept. 12, pp. 815–818). Austenitic manganese steels are now being used more and more in Germany as non-magnetic steels for making electrical machinery, and are replacing the nickel- and nickel-manganese steels. Of the new manganese steels, that containing carbon 1–1·4% and manganese 12–15% is the best known; this, after quenching in water from 1000–1050° C., is non-magnetic, but it is exceedingly difficult to machine. It has been found, however, that by reducing the carbon, the machinability can be considerably improved. In the present paper the author discusses the results of machinability and other tests on steels containing 17–19% of manganese and 0·10–1·00% of carbon. The machinability of steels with carbon 0·3% and manganese 17–18% is improved by the addition of nickel, cobalt or sulphur, but is lowered by adding chromium or silicon. Whilst the machinability of the manganese steels is improved by lowering the carbon, the elongation is poor and varies. The best elongation is obtained in a high-manganese, low-carbon steel when it also contains chromium 8% with either 1·5% of nickel or 0·10% of nitrogen—i.e., by adding elements which stabilise the austenite. Tests have demonstrated that a steel containing carbon 0·3%, manganese 17% and nickel 1·5% has strength and magnetic properties equal to, and a machinability better than the well-known nickel- and nickel-manganese steels.

New Low-Alloy High-Speed Steels. N. A. Minkevich and O. S. Ivanov. (Metallurg, 1940, No. 1, pp. 31–46). (In Russian). In the introduction the authors discuss suitable alloying elements from the point of view of their carbide stability and solubility, and refer to existing Russian low-alloy high-speed-steel compositions of which the most generally used contain 7–13% of chromium with small amounts of vanadium and tungsten. The properties of these steels are inferior to those of ordinary high-speed steel. In their experimental work the authors added titanium and molybdenum to chromium steel instead of vanadium and tungsten. Steels of the following compositions were studied :

	(1)	(2)	(3)	(4)	(5)	(6)
Carbon. %	0·78	0·89	1·02	1·00	1·02	1·08
Chromium. %	7·72	4·49	9·76	9·77	10·02	9·72
Molybdenum. %	3·67	3·76	2·02	3·70	3·86	...
Vanadium. %	1·21	2·21	1·28	0·30	1·25	0·22
Silicon. %	0·45	0·38	0·42	0·36	0·38	0·42
Manganese. %	0·54	0·13	0·42	0·22	0·32	0·28
Titanium. %	...	...	...	1·00	...	0·92
Tungsten. %	...	...	...	...	...	4·21

They were melted in a high-frequency furnace and forged at 1150–950° C. Steel (2) had particularly good forging properties. The

microstructure of all the annealed steels consisted of sorbite with fine secondary and coarser primary carbides. With all the steels the maximum rate of decomposition of the austenite occurred at 750–800° C. on cooling slowly. In quenched steel a higher chromium content increased the amount of residual austenite, while a reduction of the molybdenum content lowered it. The lowest residual austenite was obtained in steel (2) and its tempering was, therefore, simpler. In none of the steels could complete decomposition of the austenite be achieved, even by plunging into liquid air. The microstructure of the quenched steels and their tempering at different temperatures were studied. A hardness of Rockwell C-65 was obtained by tempering steel (1) for periods of 1 hr. at 560°, 570°, 580° C. after quenching from 1160–1180° C. The maximum resistance to high-temperature tempering was shown by the martensite in steel (2), the next greatest resistance by steel (5) and then came steel (3). Cutting tests were carried out in both the laboratory and the works. The best results, which were superior to those of ordinary high-speed steel, were obtained with steel (2), later designated as $EI260$. Up to a certain cutting speed, steel (5) also gave results superior to those of high-speed steel. Steel $EI260$ should be forged at 1150–950° C., and for cross-sections greater than 40 mm., this should be followed by annealing at 760–780° C. for 2 hr. to prevent cracking. Quenching should be from $1230° \pm 10°$ C. in oil, or for large complicated parts in a nitrate bath at 500–550° C. The rate of heating to quenching temperature and the holding time should be the same as for tungsten tool steel. The hardness after quenching was Rockwell C-60–C-63 and the residual austenite about 30%. Tempering was carried out at $560 \pm 10°$ C. for 1 hr. and a hardness of Rockwell C-64 was usually obtained. In conclusion, the efficiency of steel $EI260$ is compared with that of steels of various other compositions.

New Steels for Mining Work. C. H. S. Tupholme. (Mining Magazine, 1941, vol. 64, Apr., pp. 185–188; May, pp. 235–240). After a brief explanation of the function of alloying elements in improving the shock resistance of hardenable steels, the author discusses in more detail the application and heat treatment of steels containing molybdenum, nickel and chromium (either separately or in combination) for the manufacture of mining machinery parts. In impact tests at temperatures of $-70°$ C., $-90°$ C. and $-190°$ C., it is shown that it is generally necessary to quench and temper the steels in order to obtain the best impact properties, and that the molybdenum steels after this heat treatment can meet almost any form of low-temperature impact-strength specification necessary for mining under conditions of extreme cold.

Trends in Steel Mill Power Generation. C. C. Frank. (Iron and Steel Engineer, 1940, vol. 17, Nov., pp. 18–23, 32). The author discusses some of the difficulties met with in the manufacture of steam turbines for generating electric power for rolling

mills, and describes the testing of some of the raw materials and finished parts used in turbines operating at high pressures and temperatures.

Stainless Steel in Aircraft. O. Fraser, jun. (Society of Automotive Engineers : Iron and Steel, 1941, vol. 14, May 9, pp. 296–301). The author's paper, in which he deals with the difficulties the producer of stainless steel has to contend with in meeting the requirements of the aircraft industry, is reproduced. (*See* Journ. I. and S.I., 1941, No. I., p. 225 A).

Stainless Steel in Aircraft. R. A. Lincoln. (Iron Age, 1941, vol. 147, Jan. 30, pp. 35–40). The author compares the properties of chromium and chromium-nickel stainless steels with those of aluminium alloys, and shows that the former could with advantage find greater application than at present in the aircraft industry. He also points out some of the changes that would be necessary in specifications for aircraft materials in order to bring stainless steel within their limits.

The Place of Plywood, Plastics and Corrosion-Resistant Steel in Aircraft Construction. T. H. Huff. (Iron Age, 1941, vol. 147, Apr. 10, pp. 43–46 ; Apr. 17, pp. 35–40). The author considers the difficulties experienced in the preparation, storage, manufacture and surface protection of plywood, plastics and corrosion-resisting steel, and the suitability of these materials for the manufacture of certain aircraft parts. He also presents some tables of the properties of plastic materials and the principal corrosion-resisting steels.

Analyses of Proven Merit, Wide Use Comprise Standard Carbon Steels List. (Steel, 1941, vol. 108, May 19, pp. 46–47). Five tables are presented giving details of the composition of the 94 carbon steels selected by the General Technical Committee of the American Iron and Steel Institute as standards. These were chosen as representing qualities of proved merit now extensively used for a wide variety of purposes. These tables cover carbon steels in all forms, including semi-finished products. The classification of the five groups is as follows : Table I. Basic open-hearth and acid Bessemer carbon steels ; Table II. Basic open-hearth sulphurised carbon steels ; Table III. Acid Bessemer sulphurised carbon steels ; Table IV. Basic open-hearth phosphorised carbon steels ; Table V. Acid open-hearth carbon steel wire rods. Each steel is designated by a letter and four digits, the letter indicating the process of manufacture and the last two digits the carbon content.

METALLOGRAPHY AND CONSTITUTION

Some Applications of X-Ray Analysis Methods to Steelworks' Problems. A. H. Jay. (Journal of Scientific Instruments, 1941,

vol. 18, May, pp. 81–84).   In the first part of this paper the author describes the examination of silica, magnesia, and fireclay refractories and shows that X-ray data on the raw material and fired products can be of considerable value in determining the suitability of certain minerals for use as refractories.   He also discusses the changes in constitution and crystalline texture during service.   In the second part an X-ray investigation of the effect of over-annealing a chromium magnet steel on its magnetic properties in the finally hardened state and the application of the Laue method to show that crystal size can be correlated with the magnetic watt loss value of transformer steel are described.   In conclusion the value of X-rays for indicating the physical condition of the residues obtained by the alcoholic-iodine method of treating oxide inclusions in steel is demonstrated.

Experience in the Application of the Magnetic Powder Process of Testing for Cracks. H. Schrader. (Stahl und Eisen, 1940, vol. 60, July 18, pp. 634–640; July 25, pp. 655–658). After a brief description of two magnetic-powder methods of testing steel for cracks, the author discusses the sensitivity of the process, with particular reference to the dimensions of cracks which can be detected at different depths from the surface. It is shown that the correct interpretation of irregularities in the distribution of the magnetic powder on the surface of the steel is often very difficult and requires long experience. Many illustrated examples of tests on aero-engine crankshafts and various case-hardened parts are given.

The Great Nordenskiöld Block of Iron from Ovifak—Its Micrography and Metallurgy. H. Löfquist and C. Benedicks. (Kungl. Svenska Vetenskapsakademiens Handlingar, 1941, Third Series, vol. 19, No. 3). (In Swedish). In this publication a full account is given of the authors' investigation of the origin and structure of one of the three ironstone blocks discovered in Greenland by Nordenskiöld in 1870. (*See* p. 31 A).

The Potentials of Iron-Chromium Alloys Containing Hydrogen. H. H. Uhlig, N. E. Carr and P. H. Schneider. (Electrochemical Society, 1941, Apr., Preprint No. 16). The authors describe the procedure by which they measured the equilibrium potentials of a series of iron-chromium alloys containing up to 20% of chromium in an oxygen-free 4%-NaCl solution. For alloys with between 0% and 11–15% chromium the potentials were close to that of iron and the alloys were chemically active and displaced hydrogen from acid solutions. For alloys containing more than 11–15% of chromium, the potentials, particularly in neutral solutions, were close to that of silver. The data obtained indicated that newly pickled iron and stainless steels are chemically active, probably because they contain dissolved hydrogen retained during pickling. The potential change of the cell produced by interstitial hydrogen was shown to be delayed by some minutes, or even hours, after

starting the cathodic hydrogen discharge, the actual time depending on the chromium content of the alloy. It was found that the time required for the hydrogen to diffuse through the specimens increased approximately with the fourth power of the chromium concentration within the range studied for alloys with abraded surfaces. The data obtained suggest a technique for studying the diffusion of hydrogen through metals and alloys.

Physico-Chemical Investigation of Ferro-Silicon. N. V. Ageev, N. N. Kurnakov, L. N. Guseva and O. K. Konenko-Gracheva. (Metallurg, 1940, No. 1, pp. 5–12). (In Russian). The authors describe an investigation of the physical properties of ferro-silicon. Alloys with silicon contents of $43 \cdot 5$–$66 \cdot 0\%$ were prepared by melting, casting into heated moulds and cooling slowly to avoid cracking. In alloys with 43–53% of silicon, the structure consisted of FeSi dendrites against a background of large elongated crystals of the ζ-phase. The structure suggests that the ζ-phase is formed by a peritectic reaction between the molten alloy and the ε-phase. Alloys annealed for seven days at 950° C. showed decomposition of the ζ-phase into a eutectoid type of phase. Commercial 45% ferro-silicon had a peritectic structure made up of crystals of the ε-phase surrounded by the ζ-phase. Measurements of the electrical resistance and the temperature coefficient of electrical resistance of cast ferro-silicon showed no anomalies. The ζ-phase has a higher electrical resistance than the ε-phase. Microscopic and X-ray examination show that the ζ-phase has a homogeneity range of 53–$54 \cdot 5\%$ silicon. The crystal structure of this phase was determined. The X-ray examination showed that on annealing the amount of the ζ-phase is reduced due to decomposition into silicon, ε-phase and an unidentified phase.

Effect of Rate of Heating through the Transformation Range on Austenitic Grain Size. S. J. Rosenberg and T. G. Digges. (Journal of Research of the National Bureau of Standards, 1940, vol. 25, Aug., pp. 215–228). The authors studied the influence of the rate of heating through the transformation range on the austenitic grain size of high-purity iron-carbon alloys, and of commercial and experimental steels which had a wide range of carbon content and which had been deoxidised by different methods. Other factors influencing the austenitic grain size, such as initial structure, hot- and cold-working and the time held at maximum temperature, were not included in the investigation. The tests were carried out with very small specimens, about $0 \cdot 1$ in. square by $0 \cdot 04$ in. thick, in order to ensure adequate control of the rate of heating. The specimens were heated *in vacuo*, except for the maximum rates of heating, for which a lead bath held at the desired temperatures was used into which the specimens were plunged. As a measure of the rate of heating the time to heat from 1325° F. to 1450° F. was selected, as this temperature interval included the Ac_1 and Ac_3 points for the majority of the materials examined.

In conducting the tests *in vacuo* the specimens were heated rather rapidly to a temperature somewhat below 1325° F., then at the desired rate through the range 1325–1450° F., and then again rapidly to the required temperature. The investigation led to the following conclusions : (1) The grain size at 1475°, 1500° and 1600° F. of high-purity iron containing 0·50% of carbon increased with decrease in the rate of heating, whereas the grain size at 1800° F. was not so obviously dependent on the rate of heating. Generally, coarser grains were produced at the lower temperatures with slow rates of heating than at higher temperatures with fast rates of heating. With slow rates of heating the same coarse grain size was obtained at all temperatures. (2) The grain size at 1600° F. of high-purity iron containing 1·01% of carbon increased only slightly with decrease in the rate of heating. The results obtained indicated that there is a critical range of heating for this alloy at which the finest grains are obtained. (3) The rate of heating influenced the grain size at 1475° F. of commercial 0·49% carbon steels with both controlled and uncontrolled grain size. For the latter the grain size at 1600° and 1800° F. was also influenced by the rate of heating. The grain size of these steels tended to increase with an increased rate of heating. (4) The rate of heating had no effect on the grain size, at 1650° and 1800° F., of 1·05% carbon steel with uncontrolled grain size. It had an influence, however, on steel of the same composition but with controlled grain size ; at the lower temperature the coarsest grains were produced with an intermediate rate of heating, and at the higher temperature with the slowest rate of heating. (5) The heating rate had no effect on the grain size at 1600° F. of experimental steels containing 0·5 and 1·0% of carbon.

Welding Metallurgy. Volume 2. Parts II. and III. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, Mar., pp. 173–179 ; Apr., pp. 237–242). Continuation of a series of articles (*see* p. 14 A). In Part II. the authors apply the theory of transformations in steel, as explained in the first volume, to a study of the changes in the structure and mechanical properties of the steel in the parent metal adjacent to a weld. In Part III. they discuss the process of slip along crystal planes in steel subjected to tensile stress and the causes of brittleness and crack formation in welds.

CORROSION OF IRON AND STEEL

The Exploration and Combatting of the Intercrystalline Corrosion of Unalloyed Steels. E. Houdremont, W. Bennek and H. Wentrup.

(Stahl und Eisen, 1940, vol. 60, Aug. 29, pp. 757–763; Sept. 5, pp. 791–797). The authors consider the factors which in combination cause the intercrystalline corrosion of carbon steels. The three conditions which must exist to induce this form of corrosion are : (1) The structure of the steel must be in a critical state ; (2) the corrosive medium must have a critical composition ; and (3) the steel must be mechanically stressed. It is shown that the critical state of the structure depends on both the composition and heat treatment of the steel because, under certain conditions, the ferrite becomes supersaturated with some constituents which are consequently precipitated. The sensitivity to intercrystalline corrosion and the sensitivity to ageing are similar in some respects in that both decrease with increasing aluminium and carbon contents in the steel, and both increase with decreasing deoxidation and increasing nitrogen content. This supports the theory that the same microconstituents and the same changes in structure are responsible for both intercrystalline corrosion and ageing. The nature of these phenomena is not yet fully explained, but there is considerable evidence that nitrogen is one of the causes. From the evidence presented in the paper it is obvious that the corrosive medium must be one which does not attack the crystals but does attack the intercrystalline substance. The nitrates satisfy these conditions particularly well because their anions strive to passivate the steel ; their passivating effect is, however, not so strong that the more active intercrystalline substance cannot be attacked. Caustic soda also fulfils the conditions necessary for intercrystalline corrosion, especially when certain additions are made to it. The effect of mechanical stress on intercrystalline corrosion is mainly that of acceleration, as it has an activating effect on the whole of the steel, which is most marked on the intercrystalline substance ; in addition, it has the purely mechanical effect of extending a crack once it has formed. The fact that intercrystalline corrosion is in some way connected with ageing, and that the latter is accelerated by cold-deformation, leads to the conclusion that mechanical stress, especially at elevated temperatures, directly influences the behaviour of the steel by its effect on the condition of the microstructure.

The Corrosion Resistance of Electrolytic Zinc Coatings. M. Schlötter. (Stahl und Eisen, 1940, vol. 60, Aug. 15, pp. 724–727). The author studies the causes of the fact that electrolytically deposited zinc coatings have so much greater resistance to the attack of weak acids than coatings produced by the hot-dip process. He quotes the results of earlier experiments, particularly those of Burmeister and Schlötter, from which he concludes that electrolytic zinc can change its composition and structure because anions in the form of complex cations can enter a cathodic zinc deposit and become incorporated in the lattice. The current density has a very important bearing on the properties of the coating produced. Densities as high as 10,000 amp. per sq. mm. can be used, but this

necessitates special equipment. A plant suitable for the electrolytic deposition of tin, zinc, copper and lead coatings on steel wire down to 0·2 mm. in dia., in which high current densities are used, is described and illustrated.

Studies in Microbiological Anaerobic Corrosion. R. F. Hadley. (American Gas Journal, 1941, vol. 154, Jan., pp. 29–34 ; Feb., pp. 40–43 ; Mar., pp. 35–37). In the first part of his paper the author discusses the phenomenon of microbiological anaerobic corrosion from the point of view of the generally accepted electrochemical theory of corrosion, which he outlines. He points out that the basic reaction applicable to the corrosion of ferrous metals in neutral aqueous solutions applies also to the type of corrosion under discussion, *viz.* :

$$Fe + 2H^+ \rightleftharpoons Fe^{++} + 2H.$$

In the case of microbiological anaerobic corrosion, the gaseous hydrogen discharged at the cathodic surfaces enters into the metabolic process of anaerobic bacteria, so that the anodic solution of iron in the manner expressed by the above equation continues with appreciable velocity. The author discusses the products resulting from microbiological anaerobic corrosion at some length and reviews the present knowledge on sulphate-reducing bacteria, which are of particular importance in anaerobic corrosion. Concluding the first part of his paper, he gives some information regarding the frequency and intensity of microbiological anaerobic corrosion of pipe lines. In the second part of the paper he deals with the practical aspects of microbiological anaerobic corrosion. He considers in particular the physical appearance of the pipe surface resulting from bacterial corrosion processes, and presents, in tables and diagrams, the results of an investigation on the distribution and the depth of the corrosion pits formed under various conditions. In the third part he reviews the test methods commonly used in the evaluation of the corrosiveness of soils and shows them to be of little value in predicting the occurrence of microbiological anaerobic corrosion. In conclusion he discusses the influence of the decomposition of cellulose in the soil on microbiological anaerobic corrosion.

BOOK NOTICE

WILSON, W. KER : " *Practical Solution of Torsional Vibration Problems With Examples from Marine, Electrical, Aeronautical, and Automobile Engineering Practice.*" Second edition. Vol. II. 8vo. Pp. xxi + 694. Illustrated. London, 1941 : Chapman and Hall, Ltd. (Price £2 2s.)

The reviewer has read through Volume II. of this book with great interest, and finds that it contains a comprehensive treatise on estima-

tion of vibration stress, measurement of vibration stress, damping devices, vibration absorbers and flywheel calculations. The appendix also contains useful information on the subject of harmonic analysis of periodic curves.

The author has dealt at some length with the determination of vibration stresses, and has given details of the various methods of estimation. This the reviewer considers to be important, because the various damping factors in vibration become important or otherwise according to the shafting alignment and to the mode of vibration under consideration.

The portion dealing with the measurement of torsional vibration, amplitudes and stresses is particularly interesting, and the information contained in it has obviously been drawn from actual practical experience in the use of the instruments described. The Geiger torsiograph is perhaps the best known of these instruments for the measurement of all but the very high-frequency vibrations. It is gratifying, therefore, to see that the author has dealt at length with the calibration necessary due to the inclusion of a belt drive.

The M.I.T. Sperry vibration instrument is dealt with in detail; this is possibly the best instrument available for measuring and recording lateral and torsional high-frequency vibration. The reviewer has made use of this instrument for the measurement of both axial and torsional vibration of a turbine pinion shaft, and the results obtained yielded sufficient information for solving a very obscure vibration problem.

The information on pendulum dampers should prove of great assistance to designers; such dampers have been used with success in this country in the case of aero engines, but, so far as the reviewer is aware, only one Continental firm has made use of such vibration absorbers in the case of marine-oil engines. It is most likely that pendulum dampers will in the very near future be used more commonly in marine work; the information contained in this book should, therefore, prove very helpful.

It may not be out of place to mention that sizes of shafting as given by the Rules of Lloyd's Register of Shipping, mentioned by the author on page 170, do not provide a margin for the addition of more than a very small vibration stress at the normal running speed. One well-known firm of engine-builders always fit a damper to safeguard their crankshafts, and this policy has been successful. The information on dampers and vibration absorbers is worthy, therefore, of careful study by designers.

It is noted from Table 95 (page 189) that the working vibration stress permitted for continuous operation in the case of large mild-steel crankshafts is $\pm$ 3000 lb. per sq. in., and for small crankshafts with solid pins and journals $\pm$ 4000 lb. per sq. in.

The reviewer considers from experience gained over a number of years that for the large mild-steel crankshaft the vibration stress should not exceed $\pm$ 2000 lb. per sq. in. at the normal running speed. This remark applies to crankshafts having sizes as given by the Requirements of the Rules of Lloyd's Register of Shipping, and the above stress figure, viz. $\pm$ 2000 lb. per sq. in., is also applicable to auxiliary engine crankshafts.

In conclusion the reviewer would like to congratulate the author on the service he has rendered the engineering world by compiling such valuable experience into book form. Volume II. is certainly worthy of careful study by those responsible for the design of shafting and gearing installations for the transmission of periodic torques.

S. F. DOREY.

MINERAL RESOURCES

The Pictou Coalfield, Nova Scotia. W. A. Bell. (Canada, Department of Mines and Resources, Bureau of Geology and Topography, 1940, Geological Survey Memoir 225). The author gives a full account of the geology of the Pictou coalfield in northern Nova Scotia. Records reveal that coal-mining began as early as 1818; the annual production has now reached about 700,000 tons.

A Bulgarian Iron Deposit. I. Kostoff. (Mining Magazine, 1941, vol. 64, May, pp. 229–235). The author discusses the geological features of an iron-ore deposit near Rakovski in southern Bulgaria, and gives reasons for concluding that it is not of syngenetic but of epigenetic origin.

Chromite Deposits in the Seiad Quadrangle, Siskiyou County, California. G. A. Rynearson and C. T. Smith. (United States Geological Survey, 1940, Bulletin 922-J). The chromite deposits described in this report are in Siskiyou County, California. The nearest railway loading point is Hornbrook, 51 miles away. These deposits range in size from a few tons to more than 100,000 tons, and although the major portion is of low grade (20% of chromite), the material could be concentrated to a product containing 45–50% of chromite. At the current price of $20–25 per ton it is unlikely that any of the deposits can be profitably worked.

Chromite Deposits of the Pilliken Area, Eldorado County, California. F. G. Wells, L. R. Page and H. L. James. (United States Geological Survey, 1940, Bulletin 922–O). The Pilliken chromite area, near the western edge of the foothills of the Sierra Nevada, has yielded more than 10,000 tons of lump ore and concentrates. The chromite contains 30–50% of chromic oxide, so that the richest obtainable concentrates can hardly contain more than 45% of Cr_2O_3. A rough estimate of the reserve of milling ore containing over 20% of chromite is 550,000 tons, of which possibly 10,000 tons contain over 50% of chromite. A full account of the geology and the history of the mining of the region is given.

Chromite Deposits in the Sourdough Area, Curry County, and the Briggs Creek Area, Josephine County, Oregon. F. G. Wells, L. R. Page and H. L. James. (United States Geological Survey, 1940, Bulletin 992–P). A full account is given of the geology of the chromite deposits in the south-west of Oregon. In most districts in this region the chromite that is likely to prove worth mining is mainly massive ore in pods, " kidneys " and lenses, most of which contain less than 50 tons, although a few are known to contain 1000 tons or more.

ORES—MINING AND TREATMENT

The Flotation of Hematite by a Continuous Process. G. G. Bring. (Jernkontorets Annaler, 1940, vol. 124, No. 10, pp. 562–583). (In Swedish). The author gives an account of experiments with a continuous-flotation process for the concentration of Swedish hematite. The tests were made with two ores from the Stripa mine and one from Pershyttan, using a Fahrenwald flotation plant on the non-magnetic product from a magnetic separator. With proper control facilities the flotation process is just as successful with hematite as it is with sulphide ores.

The Preparation of Red Slimes. H. Schmidt. (Stahl und Eisen, 1940, vol. 60, Aug. 15, p. 727). In the working up of bauxite for the production of aluminium large quantities of red slime are produced. At one works in Germany there is a dump consisting of about 800,000 tons of this material. In this article the author briefly describes the plant designed by Gerdemann for treating this sludge so that it could be charged into a blast furnace in order to recover the iron. The sludge in question contains about 40% of iron, 7% of silica, 16% of alumina and 5–6% of titania. The material is collected by a specially adapted drag-line scraper into a bunker, from which a suspended bucket conveyor carries it to the drying plant. The turbo-drier consists of eight revolving flat ring plates in a vertical column; the material is discharged on to the top plate, and an arrangement of scrapers causes it to pass over one plate after another. Hot gases from a brown-coal-fired furnace pass upwards through the drier, bringing the temperature up to 600° C. In this way the moisture content of the sludge is reduced from 40% to 10–12%. This drier is designed for a throughput of 20–25 tons per hr. The dried product is sintered before being charged into the blast furnace. As the sludge had been considered worthless, waste building material was also dumped on the heap, and this is removed from the sludge by vibrating screens, over which the sludge passes as it is fed into the top of the turbo-drier. Part of the product from the drier is in the form of dust up to 3 mm. in grain size. This, after treatment in a rotary kiln with an oxygen-enriched atmosphere, forms a valuable raw material for red-oxide paint.

The New Ore-Mixing Plant of the Buderus'sche Eisenwerke at the Sophienhütte in Wetzlar. H. Oberle. (Stahl und Eisen, 1941, vol. 61, May 29, pp. 529–535). Owing to the difficulty in maintaining a constant supply of a uniform mixture of the several different types of ore to the blast-furnaces of the Buderus'sche Eisenwerke at Wetzlar, it was decided in 1937 to build an entirely new ore-mixing plant, a full description of which, with illustrations and diagrams, is presented. The whole plant occupies an area 124·7 m.

by 12·6 m., and it comprises twenty-six bunkers (96 cu.m. each) for large-size ore and twelve bunkers (65 cu.m. each) for fine ores, with ore-breaking and grinding machinery and the necessary conveyor belts. It is operated by a foreman and seven men, and is capable of delivering 120 tons of ore per hr.

REFRACTORY MATERIALS

(Continued from pp. 62 A–63 A)

Dolomite Bricks for Use in Steelworks. T. Swinden and J. H. Chesters. (Iron and Steel Institute, 1941, this Journal, Section I.). Further replacement of magnesite and chrome-magnesite bricks by dolomite bricks in open-hearth and reheating furnaces would reduce the strain on shipping and leave home-produced magnesite available for positions in which its use is at present essential.

Calcined dolomite, which tends to " perish," owing to hydration (even if electrically fused), can be rendered stable by firing it in a rotary kiln with a suitable admixture of serpentine and other stabilisers. Bricks made from such clinker do not contain free lime and do not " dust " owing to dicalcium-silicate inversion. They compare favourably in properties with magnesite bricks, but have a somewhat lower resistance to thermal shock and to slags high in iron oxide.

They have been used with complete success in the tap-holes, hearths and banks of fixed open-hearth furnaces and in the banks and top layers of the sub-hearths of tilting furnaces. They have also given good service in reheating furnaces operating at temperatures at which scale formation is considerable.

Dolomite bricks in which the lime is protected from hydration by a coating of flux have a higher thermal shock and slag resistance and give lives equal to those of chrome-magnesite bricks in fixed open-hearth-furnace back walls.

Limited success has also been obtained in exposed positions with stabilised dolomite bricks in which the intermediate dolomite fraction was replaced by magnesia, while 80/20 magnesite-dolomite bricks have given encouraging results in preliminary trials in tilting-furnace back walls.

Basic Open Hearth—Construction Data and Refractory Technique above the Sill Plate Level. J. H. Chesters. (Iron Age, 1941, vol. 147, May 22, pp. 39–46 ; May 29, pp. 41–46). The author describes the refractories used in the construction of a basic open-hearth fixed furnace of about 80 tons used for cold pig iron and scrap charges and fired with producer gas. The conditions the refractories must withstand and the normal causes of failure are also discussed. In

the first part the requirements of roof bricks and the relative merits of insulated and uninsulated roofs and of ribbed and plain constructions are dealt with. The second part is devoted to the design of the back and front walls, the gas and air ends, the ports and the properties of the bricks of which these are made.

Open-Hearth Insulation. E. H. Younglove. (Blast Furnace and Steel Plant, 1941, vol. 29, Apr., pp. S-37–S-39). The author makes recommendations on the practice to be followed when insulating open-hearth furnaces, stating the nature and thickness of the material to be used for covering the regenerators, slag pockets, flues, the furnace walls and roof.

FUEL

Splint Coals of the Appalachian Region : Their Occurrence, Petrography, and Comparison of Chemical and Physical Properties with Associated Bright Coals. G. C. Sprunk, W. H. Ode, W. A. Selvig and H. J. O'Donnell. (United States Bureau of Mines, 1940, Technical Paper No. 615).

Analyses of Washington Coals. H. F. Yancey and M. R. Geer. (United States Bureau of Mines, 1941, Technical Paper 618). Some data respecting the coal mines and coal production in the State of Washington, together with numerous tables of analyses, are presented. The present paper forms a supplement to Technical Paper 491 issued in 1931 (see Journ. I. and S.I., 1931, No. II., p. 492).

Carbonizing Properties and Petrographic Composition of Lower Banner-Bed Coal from Keen Mountain Mine, Buchanan County, Va., and the Effect of Blending this Coal with Pittsburgh-Bed (Warden Mine) Coal. A. C. Fieldner, J. D. Davis, D. A. Reynolds, R. E. Brewer, G. C. Sprunk and L. D. Schmidt. (United States Bureau of Mines, 1940, Technical Paper No. 616).

Hydrogenation and Liquefaction of Coal. Part I. Review of Literature, Description of Experimental Plant, and Liquid-Phase Assays of Some Typical Bituminous, Sub-Bituminous and Lignitic Coals. H. H. Storch, L. L. Hirst, C. H. Fisher and G. C. Sprunk. (United States Bureau of Mines, 1941, Technical Paper No. 622).

Relation of Flame Character to Open Hearth Operation. A. J. Fisher. (Iron and Steel Engineer, 1941, vol. 18, May, pp. 25–41). The author compares the working of a number of heats in different oil-fired open-hearth furnaces of 150–200 tons capacity by studying curves in which oil flow, air flow, furnace pressure and the oxygen, carbon monoxide and carbon dioxide contents of the flue gases are plotted against time. From these separate curves a composite chart representing ideal furnace practice was prepared, and its

significance is discussed. The terms conduction, convection, radiation, black-body radiation and absorption, selective radiation and absorption, emissivity, luminosity, and theoretical flame temperature are explained. The use of producer gas of low calorific value in high-temperature furnaces is made possible only by the natural carburetting of the gas with soot particles which cause the flame to radiate in all the wave-lengths. The author believes that the use of compressed blast-furnace gas instead of steam as an atomising and carrying agent for oil would be very effective; if this were done, it might be desirable to increase the luminosity of the flame for short periods by carburetting the oil with lamp-black; in fact, lamp-black might well be applied as a means of stabilising the luminosity of oil-flames. It is pointed out that most steam-oil mixers and burners on open-hearth furnaces do not promote uniform flame conditions between one end of the furnace and the other, especially when the steam is controlled by pressure and not by flow; a diagram and description of an efficient mixer, burner and its control units are given.

Developments in Blast Furnace Gas Cleaning. C. H. Glaser. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 46–49). The author reviews the development of gas-cleaning equipment for blast-furnace gas, describing briefly some cleaners which are based on one of the following principles : (1) Changing the direction of the gas ; (2) reducing the gas velocity ; (3) centrifugal force ; (4) filtering and washing ; and (5) electric precipitation.

PRODUCTION OF IRON

Much More Steel. F. H. Crockard. (Iron Age, 1941, vol. 147, May 8, pp. 41–48). The author discusses some methods by which the output of American blast-furnaces and Bessemer converters might be increased. The methods suggested are : (1) Removal of moisture and general control of the blast to suit climatic conditions ; (2) improved bell design to obtain better distribution of the blast-furnace burden (a sketch and description of a proposed type of bell are given) ; (3) the use of ores high in phosphorus ; (4) extended use of the acid-Bessemer process ; and (5) an increase in the capacity of Bessemer converters.

Moisture Removal from the Blast. R. N. Trane. (Blast Furnace and Steel Plant, 1941, vol. 29, Apr., pp. S-44–S-46). The author considers the merits and limitations of two systems of removing the moisture from blast-furnace blast. In one system the moisture is removed on the inlet side of the blowers, and in the other, on the delivery side of the blowers, i.e., from the air in a compressed state. It is shown that when removing moisture by

refrigeration, the second system is decidedly more advantageous. For example, a total of 670 h.p. is required to dehumidify 50,000 cu. ft. of air per min. before compression, as compared with 190 h.p. after compression, consequently the cost of the refrigeration and pumping plant and the ground space it requires are considerably less in the second case.

Mechanics of Blast Furnace Filling. T. H. Kennedy. (Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1941, vol. 29, May, pp. 501–508). The author describes an investigation of the effects of certain variables on the contours of heaps of ore, and of ore and coke, which have fallen from a chute so constructed as to simulate the conditions under which the charge falls from a blast-furnace bell when it is lowered. From the results of these tests the following conclusions were arrived at : (1) Increasing the amount of bell overhang (the vertical distance between the horizontal plane formed by the bottom of the large bell when closed and that of the hopper seating on the bell) has the same effect as increasing the diameter of the bell, namely, to deposit the material nearer the furnace walls ; (2) it follows from (1) that increasing the bell diameter without alteration to the hopper will increase the radius of the annular ridge formed by the falling material ; theoretically this increase is equal to $2\frac{1}{2}$ times the increase in the bell radius ; (3) increasing the speed at which the bell is lowered will cause the material to fall closer to the furnace wall ; (4) if ore falls from the bell alone, it will fall nearer the wall than when coke is charged on top of it ; (5) increasing the quantity charged at one time will cause the material to fall nearer the wall ; (6) the less the distance the ore falls to the stockline, the greater will be the area over which it is distributed ; and (7) the variables which have been considered are complementary in their effect on the distribution of the charge and on furnace operation.

Desulphurization with Alkali. R. H. Sweetser. (Iron Age, 1941, vol. 147, May 29, pp. 31–35). The author describes the organisation of an investigation at an American iron and steel works to ascertain (a) if it were economically and metallurgically practicable to make high-quality steel from hot metal which had been desulphurised with soda ash outside of the blast-furnace, and (b) how much more pig iron a blast-furnace would make on " lean-slag " practice.t The research was sponsored by the Blast Furnace and Raw Maerials Committee of the American Institute of Mining and Metallurgical Engineers, and was commenced in 1940. Some of the data obtained are presented, the author basing his information on two papers read at the 1941 Conference of the Open-Hearth Steel and Blast Furnace and Raw Materials Committees of the A.I.M.E. by M. Wheldon and G. Hanna, and by L. Labeka and J. E. Walker. The general conclusion reached was that desulphurisation outside the blast-furnace can be applied without any adverse effect on the open-hearth operations in American practice, especially where the

coke is high in sulphur and where the steelworks demand a very low sulphur content in the hot metal.

Contribution to the Knowledge of the Desulphurisation Reactions in the Blast-Furnace. W. Oelsen and H. Maetz. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 465–474). This paper is an abridged version of a report of a study of the reactions of iron sulphides with oxides, carbonates, silicates and phosphates in the presence of carbon, which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 23, pp. 335–351. (*See* Journ I. and S.I., 1940, No. I., p. 227 A).

The Viscosity of Slags and Glasses. Part I. A Discussion of the Methods of Measuring the Viscosity of Molten Silicates. J. R. Rait. (Transactions of the British Ceramic Society, 1941, vol. 40, May, pp. 157–202). The author reviews the literature on methods of measuring the viscosity of molten silicates, and describes in detail the theory and practice of measuring viscosity at high temperatures by the following more important methods : (*a*) The concentric cylinders method, in which the inner cylinder is rotated at constant velocity. Since the range of this type of apparatus at high temperatures is from 10 to 10^7 poise, it is suitable for measuring the viscosity of glasses and some blast-furnace slags, but is unsuitable for measurements of open-hearth slags. (*b*) The concentric cylinders method, in which the outer cylinder is rotated at constant velocity. The range obtainable is from 0·1 to about 10^4 poise at high temperatures, and the procedure is therefore suitable for glasses, blast-furnace and open-hearth furnace slags. (*c*) The falling-sphere method, by means of which the viscosity of glasses may be measured, but the range of which is too high for blast-furnace and open-hearth furnace slags. (*d*) The logarithmic decrement method, which has a range from about 0·1 to 50 poise at high temperatures, and is therefore suitable for open-hearth and blast-furnace slags. A bibliography of 113 references is presented.

The Viscosity of Slags and Glasses. Part II. Viscosity-Temperature Relationships and the Constitution of Molten Slags and Glasses. J. R. Rait. (Transactions of the British Ceramic Society, 1941, vol. 40, May, pp. 205–227). The author reviews the literature on the relationships between viscosity and temperature and between viscosity and composition, with particular reference to the constitution of liquids, including molten slags and glasses. It is shown that molten glass may be considered as an associated liquid, the degree of association decreasing with increasing temperature. Recent work on the internal-energy and viscosity-composition relationships of molten soda-silica glasses indicates that the compound $Na_2O.2SiO_2$ probably exists in the liquid state. Viscosity-composition isothermal curves of $CaO–SiO_2–Al_2O_3$ slags are presented, and reveal discontinuities at compositions corresponding to changes of phase.

The Manufacture of Ferro-Silicon. (Engineering, 1941, vol. 152, July 4, pp. 6–7). A brief description is given of a process of making

ferro-silicon. One type of electric furnace employed for making ferro-silicon is the arc-resistance furnace, wherein heat is generated not only by the arcs, but also by the resistance offered to the passage of the current by the charge itself. The furnace lining must be made exclusively of carbon; this carbon is prepared from graphite, ground to a fine powder in a pan-mill, and formed into a tough mass with the addition of a little pitch. The bottom electrode consists of one or two copper plates. The upper electrodes are of the usual cylindrical graphite type, but must be housed within more or less tight-fitting economisers so as to exclude the air as far as possible. Charging the furnace simply consists of shovelling in the quartzite, high-grade coke and soft-steel scrap. More variations occur in the current than with almost any other type of electric hearth. Once the highly oxidisable mass is covered with a layer of slag, there is less danger of air injuring the charge, and it is then that the furnace is tapped and fresh material added. In this manner the process proceeds continuously. On tapping, the ferro-silicon is cast in the form of slabs in carbon moulds. The 25%-silicon grade can be produced with a consumption of 2·3 kW. per hr. per lb., and the 70% grade requires 16 kW. per hr. per lb., using a small furnace of about 200 kW.

Osmund Iron. K. Winge. (Jernkontorets Annaler, 1941, vol. 125, No. 3, pp. 99–141). (In Swedish). The author presents the results of his historical investigations of the origin and uses of Osmund iron. It is generally believed that Asmunder or Åsmund was a Swedish master-blacksmith living at about the end of the eleventh century. Bars of Osmund iron were a recognised form of currency in Sweden until towards the end of the eighteenth century.

Recent Research into Problems of Powder Metallurgy. D. W. Rudorff. (Metallurgia, 1941, vol. 23, Apr., pp. 167–170; June, pp. 53–56). The author reviews the results of recent laboratory research by Balshin in the U.S.S.R. into certain theoretical and practical problems of powder metallurgy. He studies methods of calculating the pressure exerted by the plunger on the powder in the mould; this is obtained from the sum of the following items : (1) The energy consumed in overcoming the cohesive force acting between the powder particles; (2) the energy consumed in the deformation of the particles and, as is often the case, in the combining of groups of particles into conglomerates; and (3) the energy expended in overcoming the elastic forces and residual stresses present in the conglomerate.

Standard Cost Procedure. F. Ryder. (Blast Furnace and Steel Plant, 1940, vol. 28, Sept., pp. 896–899, 933; Oct., pp. 996–999; Nov., pp. 1087–1089; Dec., pp. 1174–1180; 1941, vol. 29. Feb., pp. 200–204; Mar., pp. 321–323; Apr., pp. 414–416). After a general consideration of the development of cost accounting in the United States, the author explains the standard cost procedure which is usually adopted as a basis for costing. This procedure

involves the following steps : (1) Obtaining managerial support for the establishment of the system; (2) determinations of standards of performance for the various conditions of operation and load likely to be experienced ; (3) selection of a normal load factor ; (4) keeping of continuous records of actual performance ; (5) selection of the appropriate standards for the actual conditions of production for the period under review ; (6) determination of the " load variance," *i.e.*, the difference between the standard cost at normal load and that at the actual load ; (7) determination of the " operational variance " by deducting the standard cost at the actual load from the actual cost ; (8) taking corrective measures to reduce or eliminate losses ; and (9) posting the bulk figures into cost ledgers so that ultimately these will link up with the financial accounts. The author then describes the application of this procedure to steel production, dealing in particular with the estimation of the losses in the process of the conversion of iron to steel and those due to scaling.

FOUNDRY PRACTICE

(Continued from pp. 71 A–72 A)

Blast Control in Cupola Melting. E. Piwowarsky. (Giesserei, 1940, vol. 27, May 3, pp. 157–159). In this mathematical treatise the author shows that it is possible to calculate the upper and lower limits of the amount of air required for the complete combustion of a layer of coke of given dimensions, density and carbon content in a cupola. He presents several tables and graphs showing how the diameter of the cupola and the size and number of the tuyeres are related to the consumption of blast, coke, iron and limestone.

Slagging in Cupola Operation. (Foundry Trade Journal, 1941, vol. 64, June 19, pp. 408, 416). Some reasons are given for the development of a pre-calcined flux incorporating a number of active chemical bases as an addition to the ordinary limestone available in England, the object being to produce an actively cleansing fluid cupola slag. The results achieved with this flux vary from foundry to foundry, but in one instance a reduction of 30% in the amount of sulphur in the iron and an increase of 11% in the tensile strength have been reported. In another case where a high proportion of steel was included in the charge and the iron produced picked up sulphur to as high a figure as 0·18%, this amount was brought down to 0·13% by using 1% of the new flux. As this flux is prepared outside of the cupola, the latter is relieved of the burden of having to supply the heat required for the decomposition involved in calcination. The pre-treatment of the fluxing materials also ensures direct chemical combination with the slag-making impurities in the melting zone and, as these are exothermic reactions, the temperature of the metal is also increased.

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De-Oxidation in the Foundry Cupola. W. McConnachie. (Foundry Trade Journal, 1941, vol. 64, June 12, p. 398). The author considers the composition of the gases at the charging-door level in a cupola, and deduces from the analysis and other evidence that the conditions in the hot zone of a cupola are not strongly oxidising, as is generally supposed.

Foundry Technique in the Production of High Strength and Other Types of Alloy Grey Iron Castings. A. E. McRae Smith. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, July 10, pp. 19–21, 30). This article comprises an abridged version of an addendum to a previous paper (see p. 3 A). In it the author gives some additional details concerning the melting practice for the production of iron to meet the new specification for Grade IV. iron in British Standard 786, which is a high-strength alloy cast iron for motor-vehicle castings, Diesel engine castings, &c.

Annealing Malleable Castings in Elevator Furnace. R. E. Cox. (Foundry, 1941, vol. 69, Apr., pp. 38–39, 113). The author describes and illustrates an electrically heated furnace for annealing quantities of small malleable iron castings. The furnace consists of two chambers, one for heating and holding the charge at the desired temperature and the other for slow cooling. These chambers are raised well above the floor level and are charged by an elevator from underneath. The charge is loaded into round perforated boxes of a heat-resisting alloy, which are placed on a grid supported above the brickwork of the hearth by short alloy-steel columns passing through the brickwork and fixed to the steel frame of a car which, when raised by the elevator, forms the bottom of the furnace. After 7 hr. for heating and 5 hr. holding, the charged car is lowered to the track, moved along underneath the cooling chamber and then raised into it. The temperature regulation is fully automatic, and the cooling through the critical temperature range is carried out at a predetermined rate. A charge of 4 tons is annealed in 12 hr. with a current consumption of 300 kW. per hr. per ton (2000 lb.) of castings. No protective atmosphere is used, and the castings, although slightly discoloured, are free from scale.

The Production of Steel Castings. C. H. Kain. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 64, June 19, pp. 411–412; June 26, pp. 429–430). The author gives a general description of the processes involved in the production of steel castings from the preparation of the liquid steel in crucibles, electric furnaces, Bessemer converters or open-hearth furnaces to the fettling, heat treatment and testing of the finished casting.

Electric Steel Castings Meet Defence Requirements. R. R. West. (Foundry, 1941, vol. 69, May, pp. 85–87, 177). The author describes the melting practice at an American steel foundry using two $1\frac{1}{2}$-ton-per-hr. Electromelt furnaces with acid linings.

American Synthetic Sand Practice. N. J. Dunbeck. (Institute of British Foundrymen Conference, July, 1941, Paper No. 730).

The author describes current American foundry practice in the preparation of synthetic moulding sands for both ferrous and non-ferrous castings, and discusses the properties of some of the bonding clays available in different districts.

Patterns Demand the Best in Skill, Tools and Materials. V. Reid. (Foundry, 1940, vol. 68, Dec., pp. 35–37, 112, 113; 1941, vol. 69, Jan., pp. 43–45, 115–118). The author discusses the training of pattern-makers and the selection of timber and tools for making patterns.

A New Foundry Equipment Works. (Foundry Trade Journal, 1941, vol. 64, June 12, p. 392). A brief description is given of the new works of the Coleman Foundry Equipment Co., Ltd., and of a large moulding machine with a pattern plate 66 in. by 115 in. constructed by this company.

Mould and Core Washes. W. Y. Buchanan. (Institute of British Foundrymen Conference, July, 1941, Paper No. 731). The author describes the preparation of " blackwash," which consists of a mixture of blacking, often made from finely ground coke, in water with an addition of bonding material; it varies in consistency from a thin liquid to a heavy mud. Drawings and details of the mixing machinery are given.

Foundry Problems—Pipes and Forming-Die Practice. A Sutcliffe. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 64, June 12, p. 393). In opening a discussion of foundry problems, the author describes some difficulties met with in the casting of a pipe 9 ft. long by 14 in. in dia., and indicates three ways of putting flange cores into place by means of templates so as to ensure correct centring.

Centrifugal Casting with Axis Vertical. N. Janco. (Metal Progress, 1941, vol. 39, Apr., pp. 432–434). The author points out that centrifugal casting on a vertical axis is often better than spinning the mould on a horizontal axis. He briefly describes three methods of centrifugal casting on a vertical axis. In one method no core is used and the quantity of metal poured has to be accurately known, so that the hole down the centre of the casting will be of the size required. The second method is for castings with a centre hole not of uniform diameter, for which a core must be used. In the third method one flask is used for making several small similar castings, the separate moulds are placed symmetrically round a central feeding reservoir, to which they are connected by separate runners ; this is really a method of pressure casting.

Hydro-Blast Cleaning in a Jobbing Foundry. (Iron Age, 1941, vol. 147, May 22, pp. 48–51). An illustrated description is given of a hydraulic plant installed at an American foundry producing 40–50 tons of castings per day for removing cores and sand from large castings. In this cleaning process a relatively fine jet of water at 1200 lb. per sq. in., into which about 225 lb. of sand per min. are injected, is used for removing the cores and moulding sand from

the castings. Wet sand from a tank is drawn to the nozzle on the injector principle, and only the nozzle itself is subject to rapid wear. Of equal interest to the plant for supplying the sand-water mixture is the equipment for recovering the sand, for this sand is re-used for cores and facings. The scouring sand and broken-up cores pass through a grating in the floor of the cleaning room and over a screen which removes any scrap metal; the sludge is then pumped to the top of a classifying tank. The sand cleaning and classifying, are done on the flotation principle. To reach the sand tank below, the sand must pass through three vertical venturi tubes, through which water is pumped upwards at a regulated pressure. By adjusting the pressure, the coarseness of the sand-grains that drop through the upward stream can be controlled. All other sand, clay fines and scum are carried to the top of a tank, where they overflow through a sludge-flume to a spreader box and a deep settling tank. Many advantages are claimed for the hydro-blast method of cleaning, among which is the increased cleanliness of the air, with consequent decrease in the risk of silicosis.

Roll-Train Transport for Foundries. H. Schulze-Manitius. (Giesserei, 1940, vol. 27, June 14, pp. 217–221). The author discusses the application of roll-train transport in foundries, illustrating and describing several types of equipment, such as straight and curved trains, switches, and gravity-operated and power-driven trains.

The Theory of the Solidification of Castings. N. Chworinoff. (Giesserei, 1940, vol. 27, May 17, pp. 177–186; May 31, pp. 201–208; June 14, pp. 222–225). In this treatise, which is mainly mathematical, the author establishes from theoretical studies, combined with the results of tests, the following laws relating to the solidification of castings : (1) There is a parabolic relationship between the solidification time and the mass coefficient of castings made of metal of the same composition, cast at the same temperature into moulds of similar thermal properties; (2) the rate of solidification is proportional to the coefficient of thermal conductivity of the mould; (3) a law for the solidification of castings of non-uniform section and irregular shape; (4) a law relating the solidification of geometrically similar castings; and (5) the cooling time is proportional to the solidification time of geometrically similar castings.

Using test data and the equations he has developed, the author determined the movement of the boundary between the solid and liquid phases across the section of a casting as it cools. From this it was established that with a casting of steel having a wide solidification-temperature range, complete solidification of the surface does not take place for a long time. It was also shown that the interior of a steel casting which was always assumed to be of liquid steel while cooling actually contains a large percentage of the solid phase. The author's equations enable the effect of superheating the steel and of lowering the solidification point on the solidification time to be determined.

PRODUCTION OF STEEL

Photocell Control for Bessemer Steelmaking. H. K. Work. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1300½ : Metals Technology, 1941, vol. 8, June). After a brief review of some of the attempts which have been made to find a satisfactory means of controlling the blow of a Bessemer converter, the author describes his own method in detail. This method is based on the sighting of a photo-electric cell on the flame issuing from the converter, amplifying the current fluctuations in the cell circuit and recording these fluctuations on a chart ; the record so obtained is a radiation-intensity/time curve for the duration of the blow. The receiving unit for picking up the radiation consists of a group of three cells mounted side by side in a housing and set up so that the field of view includes the whole flame ; this unit is placed about 60 ft. from the converter. Two filters are placed at the aperture of the cell housing ; one of these is a heat-absorbing filter and the other an ultra-violet-ray absorbing filter. Radiation-time curves for several blows are reproduced. From a study of many of these curves the author establishes certain relationships between the silicon content and the blowing time, and between the distance of the highest point of the curve from the base line and the temperature of the blown metal. As the nitrogen content of steel in general increases with the temperature of the blown metal, the height of the radiation curve is a factor which is of great assistance in controlling the nitrogen content. All the curves show an arrest as the flame falls at the end of the blow, and one of the factors that affects the position of the end point is the sulphur content, for high-sulphur blows containing added sulphur cause the arrest to be at a lower position in the curve than is the case with steel containing a normal amount of sulphur. It is recognised that the application of the photo-electric cell as a means of controlling the Bessemer process does not give indications of changes in the phosphorus content, but the equipment described has been successfully used at several American plants for two years, and since its installation there has been a marked reduction in the number of heats which had to be diverted owing to abnormal carbon and manganese contents.

The Introduction of the Basic Open-Hearth Process in Sweden. C. Sahlin. (Jernkontorets Annaler, 1940, vol. 124, No. 10, pp. 537–561). (In Swedish). The author surveys the history of the introduction and development of the basic open-hearth process of steelmaking in Sweden, first from the standpoint of the country as a whole. He then describes in greater detail how the process was developed at six of the important Swedish works.

Open Hearth Furnace Control. M. J. Bradley. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 35–43). The author describes some systems of instrumentation for controlling the operation of the open-hearth furnace. The first is an automatic signalling system which notifies the operator when to reverse the flow of gases through the checker chambers ; it is based on maintaining within a predetermined range the temperature difference between the checker chamber being heated by the exit gases and that being cooled by the incoming air for combustion. The second is a system for measuring and controlling the pressure of the gases in the furnaces, and the third is for controlling the fuel/air ratio.

Water Requirements of Steel Plants. L. N. McDonald, jun. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 51–55). The author gives a general description of the water services required by a modern steelworks, discussing the quantity and purity required, the sources of supply and systems for the circulation and re-use of waste water.

Systems and Equipment for Steel Mill Water Distribution. H. M. Graham. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 55–59). The author describes some water intakes and pumping machinery for the supply of large quantities of river water for use in rolling mills.

Effect of Water upon Equipment and Product in the Steel Plant. H. H. Shakely and C. J. Wyrough. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 59–63). The authors consider the purpose for which water is used at coke-ovens, blast furnaces, steel furnaces, rolling mills and pickling plant in the Pittsburgh district, dealing in particular with those points in the system at which trouble is likely to arise owing to corrosion, accumulation of deposit, &c.

Corrosion and Scale Formation in Steel Plant Water Supply. E. W. Butzler. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 64–67). The author discusses methods of preventing corrosion and the formation of deposit in water pipes used for the distribution of water in a steelworks. He refers in particular to " threshold treatment," which is the addition of small quantities (*i.e.*, 0·5–5·0 parts per million) of molecularly dehydrated phosphates, such as sodium hexametaphosphate, which prevents the deposition of calcium carbonate. The treatment has been given this name because the phosphate acts in such a manner as to remove the crystal nuclei from contact with the solution on the threshold of the crystallisation process.

Production of Strategic Steel. J. G. Dun. (Metal Progress, 1941, vol. 39, May, pp. 592–594). The author summarises the information on the production of steel for armaments and on the conservation of manganese and chromium which was made known at the 1941 Open-Hearth Conference, sponsored by the American Institute of Mining and Metallurgical Engineers.

Trends and Experiments in Making Steel in the U.S.S.R. S. L. Case. (Metals and Alloys, 1941, vol. 13, Apr., pp. 419–423). The

author summarises some reports on research in the iron and steel industry of the U.S.S.R. which have appeared in Russian technical publications during recent years. Abstracts of most of these reports have already appeared in the Bulletin. A report of an investigation by Dobrokhotov is of interest. In this he gives constructional details of a method for steel-making in which the preliminary refining is carried out in a continuous-oxidising furnace of large capacity (1440–2880 tons per day). Approximately 125 tons of iron are charged into this furnace every 1 or 2 hr.; ore, limestone and bauxite preheated to 2200° F. enter the oxidising furnace in a continuous stream from a rotating cylindrical furnace. This furnace, somewhat similar in design to a Brackelsberg furnace of large capacity, is heated by the combustion products of the oxidising furnace. From the oxidising furnace the semi-finished metal is passed through a runner into a refining furnace located at a lower level.

Control of Hydrogen in Steel. H. D. Hibbard. (Steel, 1941, vol. 108, June 16, pp. 69–70, 103, 104). After briefly reviewing the detrimental effects of hydrogen in steel and the possible sources of this hydrogen, the author proposes a melting procedure for removing as much of this gas as possible. He suggests that the duration and vigour of the boil be adjusted to suit the amount of moisture in the atmosphere at the time, *i.e.*, to prolong the boil in hot damp weather.

Control of the Open-Hearth Slag during the Melt by Rapid Chemical Determinations of the Ferrous Oxide, Manganous Oxide, Lime and Silica. E. Maurer. (Stahl und Eisen, 1940, vol. 60, May 2, pp. 391–392). The author discusses various methods of making analyses of open-hearth slags sufficiently rapidly to be of use in controlling the melt. He gives in detail the procedure adopted by an American steelworks for making a silica determination in 30 min. with an accuracy of $\pm 0.1\%$, and also describes a simple magnetic apparatus for removing the iron from finely ground samples of slag that have been rapidly solidified in a copper mould.

The Calculation of Reaction Energies and Equilibria by Means of Entropy Values. H. Ulich. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 499–501). The author discusses formulæ for calculating reaction energies and equilibrium constants from heats of reaction, specific heats and entropy values.

Arc Furnace Transformers. C. C. McLaren. (English Electric Journal, 1941, vol. 10, June, pp. 84–93). The author discusses the design of modern transformers for electric-arc furnaces for steel-making.

The Use of the Reflecting Microscope in the Examination of Open-Hearth Slag. M. Tenenbaum and T. L. Joseph. (Blast Furnace and Steel Plant, 1941, vol. 29, Apr., pp. 403–407; May, pp. 522, 523, 545, 551, 552). The authors describe the application of the reflecting microscope for the study of the phase changes in

open-hearth slags in the course of a heat from acid slag in the early stages to very basic slag as tapping time approaches. Suitable samples for this type of observation can be prepared in less than 5 min., so that the results can be used for determining what corrective additions to make. Micrographs of the same slag obtained with transmitted and reflected light are presented for comparison.

An Investigation to Improve the Life of Ingot Moulds. A. Ristow. (Stahl und Eisen, 1940, vol. 60, May 9, pp. 401–404; May 16, pp. 427–429). This paper is a report on the combined work of the Open-Hearth Process and Basic-Bessemer Process Sub-Committees of the Verein Deutscher Eisenhüttenleute in their investigation of the factors affecting the life of square-section ingot moulds for ingots of over 2½ tons. Questionnaires were sent to a number of German works and statistics were compiled from the answers obtained, and the results of special investigations are also given. The three principal factors studied were the material of which the moulds were made, the shape and dimensions of the mould, and the casting conditions. With regard to composition of the material, a high manganese content was detrimental to the mould life, whilst a high silicon/manganese ratio was found to be favourable. For small moulds for top-pouring a graphitic carbon content of 2·8–3·2% gave the best life. The ratio of the combined to the total carbon content should be as low as possible. The ingot shape most conducive to a long life of the mould is one with a high degree of taper and with a height/mean-thickness ratio as high as possible. The ratio of the mould weight to the ingot weight should be either 1/1 or above 1/1·3. In works operating the basic Bessemer process, increasing the teeming rate slightly lengthened the life of the mould, whether top-poured or bottom-poured. As regards standing time, the best results were obtained when the ingots were stripped as soon as possible after pouring, or after 1½ hr. standing time. Immersing the moulds in water was detrimental compared with cooling on the bank; cooling with a jet of water from a hose was still more detrimental. Ingot moulds should not be used more often than two or three times in a day.

The Problem of the Life of Steelworks Ingot Moulds. O. Hengstenberg, K. Knehans and N. Berndt. (Stahl und Eisen, 1941, vol. 61, May 15, pp. 489–493). The authors report on an investigation of the factors affecting the life of ingot moulds. From observations made on over 500 moulds the following conclusions were arrived at : (1) Burnt out moulds have as a rule a higher total carbon content than cracked moulds ; (2) the ratio of burnt to cracked moulds increases with increasing silicon content, whilst the mould life is shortened ; (3) increasing the manganese content decreases the proportion of burnt-out moulds ; (4) a longer life for cracked moulds is associated with increased combined carbon content ; (5) with total carbon 3·55–3·65% and silicon 1·55–1·70% an increase in the phosphorus up to about 0·1% actually improves the

life ; (6) the most favourable relationship between total carbon and silicon contents from the standpoint of the life of the mould is 3·50–3·60% of the former with 1·50% of the latter ; if the total carbon is slightly less, the silicon should be slightly higher, and *vice versa* ; (7) the frequency with which a mould is used has an important bearing on its life. It was found, for example, that the average life of 78 moulds under the normal casting routine was 103 casts, whilst that of 32 moulds which were used only once per day was 145 casts ; (8) moulds used for bottom-pouring last considerably longer than top-poured moulds.

The casting conditions in the making of the moulds, the size of the graphite particles and the structure of the iron are also discussed and related to the life of the mould.

Reducing the Defects in Large Ingots of Basic Open-Hearth Steel. E. Wulffert. (Stahl und Eisen, 1940, vol. 60, Sept. 19, pp. 833–838). The author reports on an investigation of the causes of defects in large ingots of basic open-hearth steel for forging. Non-metallic inclusions are not considered, and the investigation is confined chiefly to defects in the core, the position and nature of which can be determined by radial and axial drilling. The principal factors affecting the soundness of the cores of large ingots were found to be : (a) The total iron content of the final slag ; (b) the rate of carbon removal ; and (c) the teeming temperature. From many observations and tests it was noted with regard to (a) that when the total iron content of the slag was less than 7·5%, 70% of the ingots were defective, and with 6% total iron all were defective. The iron content of the slag is mainly dependent on the lime/silica ratio, and it is recommended that steps should be taken early in the heat to obtain a lime/silica ratio of 2·4–2·6/1, which will produce a final slag containing total iron 8–10%. It is suggested that the composition of the slag affects the under-cooling capacity of the steel, which in turn affects the primary structure. With regard to (b), it is recommended that the rate of carbon removal should not exceed 0·27% per hr. Rapidly decarburised melts were observed to have gassy slags and to give off a lot of gas in the runner and from the mould, and were also associated with higher temperatures, so that it is advisable to throttle down the supply of heating gas in good time when working a rapidly decarburising melt. As to (c), the most favourable teeming temperature was found to be 1570–1600° C. In a discussion on the cooling of large ingots the author explains the cause of the formation of a dendritic structure below the surface of the ingot. Pouring at the above temperature leads to the proper conditions of cooling, which tend to suppress the formation of dendrites and favour solidification with a globular structure, in which case there will be either no internal defects at all, or they will be so small that the process of forging will eliminate them.

Information on Surface Defects in Ingots and Material for Rolling. R. Schäfer. (Stahl und Eisen, 1940, vol. 60, Aug. 22, pp. 737–744).

The author discusses surface defects in ingots and billets, differentiating between those having their origin in the steelmaking process and those traceable to subsequent processes such as heating in the soaking pit and dressing preparatory to rolling. He shows that the original cause of a defect frequently cannot be traced, and stresses the importance of constant care and attention to all details by the melting-shop and rolling-mill staffs.

FORGING, STAMPING AND DRAWING

Forging Barrels for the Bofors Anti-Aircraft Gun. (Machinery, 1941, vol. 58, May 22, pp. 197–200). An illustrated description is given of the forging and heat-treatment operations at a Canadian works manufacturing barrels for Bofors anti-aircraft guns. These barrels are forged from ingots 41 in. long, $12\frac{1}{2}$ in. square at one end and $9\frac{1}{2}$ in. square at the other down to a bar over 10 ft. long in a series of three operations between which various heat treatments are carried out.

Modern Practice in the Generation and Application of Hydraulic Power. J. E. Holveck. (Iron and Steel Engineer, 1941, vol. 18, May, pp. 58–66). The author describes and discusses hydraulic-power generating systems and their control for the forging, pressing and extruding of metals. Particular attention is given to a synchronised pump unloading and loading device for an accumulator system. Synchronised unloading is the interruption of the pump delivery in such a manner that unloading is accomplished by a gradual deceleration of fluid delivery and power input from full to zero, coinciding with the diminishing rate of flow of the last plunger displacement. Synchronised loading is the resumption of the pump delivery from zero to full rate, coinciding with the increasing rate of flow of the first plunger displacement into the pressure systems. This device is controlled electrically by means of a pressure governor and solenoids.

Parts Made from Steel Turnings by Compressing and Sintering. (Steel, 1941, vol. 108, May 26, pp. 76–78, 94). A description is given of a process of manufacturing small rings and sleeves by compacting and sintering steel turnings. The turnings are first crushed into an aggregate of fairly uniform size somewhat larger than coarse sand, so that a constant weight/volume ratio can be maintained. This material is then fed into the hopper of a briquetting press; the dies of this machine produce a compacted article about twice the size of the desired finished piece. The next process is that of sintering, which is done in about 15 min. in a furnace with a capacity of about 500 pieces per hr. kept at 1850–1900° F. The parts are

quickly transferred from the furnace to a hot press with hinged water-cooled dies which brings them still nearer to the desired size. In the next process any small fins are cut off in a cold-trimming machine, and finally a cold-coining press gives the part a finished smooth surface which does not require machining. The fact that the raw material consists of steel turnings and that no machining is required has very greatly reduced the cost of manufacture.

Comparative Deep-Drawing Tests by Various Processes on Alloy Steel Sheet and Strip. A. Pomp and A. Krisch. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 503–512). This paper is an extended abstract of an account of a series of deep-drawing tests which the authors carried out on specimens of chromium-nickel and chromium-manganese steels, chromium steels and silicon steels. The full account appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 3, pp. 19–34. (*See* Journ. I. and S.I., 1940, No. I., p. 239 A).

The Effect of Different Drawing Conditions on the Deforming Efficiency and the Strength Properties when Drawing Steel Wire. F. Schwier. (Stahl und Eisen, 1941, vol. 61, June 12, pp. 577–587). After a brief review of the literature on the influence of various factors in the drawing process on the properties of drawn steel wire, the author gives a full report of his own investigation of the effect of such factors as drawing speed, die entrance angle and lubricant on the drawing efficiency of wire of three types of steel containing carbon 0·06%, 0·40% and 0·60%, respectively. The following conclusions were arrived at : (1) There was a reduction in the power required as the drawing speed was increased, and this improved the drawing efficiency ; (2) the strength of a wire drawn at 1·6 m. per sec. was slightly higher than that of wire drawn at 0·4 m. per sec. ; (3) the drawing efficiency was increased with increasing reduction in section ; (4) the best die entrance angle was 10°, but the drawing efficiency increased more slowly with large reductions in area as the entrance angle was increased ; (5) wires drawn with the greatest drawing efficiency had the most uniform properties ; (6) the harder the material of which the die was made, the greater was the drawing efficiency ; (7) drawing wire through a harder die did not affect the properties of the wire ; (8) pulverised soap was found to be the best lubricant, and engine oil the worst of those tested ; (9) when inferior lubricants were used the best drawing efficiency was obtained by increasing the die entrance angle ; (10) tests made at between room temperature and 130° C. showed that less power was required with increasing temperature, and the reduction in power was greater with increasing reduction in area, but above 100° C. there was no further decrease in the deformation efficiency ; (11) the strength of the wire increased with increasing drawing temperature, especially with the high-carbon steels, whilst the elongation decreased.

ROLLING-MILL PRACTICE

" **Roll More Tons.**" A. E. Lendl. (Iron and Steel, 1941, vol. 14, June, pp. 352–355, 365). In the second part of this paper (*see* Journ. I. and S.I., 1941, No. I, p. 159 A) the author discusses roll calibrations by Dehez and uses them to demonstrate the suitability of a formula, which he applies to calculate a roll calibration for 2 in. × 2 in. angles.

Production of Seamless Tubes by Combined Effects of Cross-Rolling and Guide Disks. W. Trinks. (Blast Furnace and Steel Plant, 1941, vol. 29, Apr., pp. 408–413, 420). The author describes the theory and practice of the Diescher elongator method of cross-rolling for producing finished seamless steel tubes. The Diescher mill requires cross-rolls arranged in a manner on the whole similar to those of the Mannesmann mill. In the Diescher mill a pierced blank enters on a freely floating mandrel on which it is cross-rolled while the mandrel moves in the forward direction. The cross-rolling process is inherently an expanding process, because the contact area between roll and blank is long in the direction of tube travel and short in the direction of roll travel. If cross-rolling only were applied on a floating mandrel, a tube with uncontrolled expansion and of much larger diameter than that of the pierced shell would be formed, but in the Diescher mill this expansion is prevented by the elongator discs, which, by frictional contact with the blank, not only prevent uncontrolled expansion, but also pull the blank forward and convert the expanding tendency of the cross-rolls into elongation of the tube.

Application of Power Requirements to Main Roll Drives. L. A. Umansky. (Iron and Steel Engineer, 1941, vol. 18, June, pp. 25–32). The author discusses the possibilities of the application of mercury-arc rectifiers in the electricity supply systems of rolling mills. He looks upon the rectifier as a new tool which is somewhat more efficient than the motor-generator set for the conversion of A.C. supply to D.C. supply. It has certain merits and it is reasonable to expect it will gradually be used with some types of main roll drives.

Reversing Drives for Slabbing Mills. F. R. Burt. (Iron and Steel Engineer, 1941, vol. 18, May, pp. 51–56). The author describes the electrical drives at three American slabbing mills. The first mill has a very high lift and can take ingots up to 25 in. × 66 in. in section on edge, and it is driven through pinions by a single 7000-h.p. D.C. reversing motor. The second mill has horizontal rolls 45 in. in dia. with vertical rolls 36 in. in dia. close to the former in the conventional manner. Each horizontal roll is driven by a 5000-h.p. D.C. reversing motor, and both vertical rolls by a 3000-h.p. reversing motor ; the

three motors are connected in parallel across a 700-V. bus bar supplied with current from three 3500-kW. generators in parallel. The third mill has horizontal rolls 45 in. in dia. and vertical rolls 40 in. in dia., the latter in a stand situated 33 ft. from the former, leaving room for a slab turntable in between. The former rolls are driven by two 5000-h.p. reversing motors running at 40–80 r.p.m. and the latter by a 2000-h.p. motor at 100–200 r.p.m.

Electric Drives for Cold Strip Rolling Mills. H. S. Carnegie. (English Electric Journal, 1941, vol. 10, June, pp. 70–76). In the first part of the paper the author deals with the subject of tension control in a modern cold strip mill and discusses the advantages of the electrically-driven constant-tension reel. In the concluding part he describes and illustrates a number of cold-strip mills of both the reversing and non-reversing types which incorporate electrically-driven reels.

PYROMETRY

A Proposed New Type of Pyrometer for Measuring Gas Temperatures. A. Blackie. (Journal of Scientific Instruments, 1941, vol. 18, June, pp. 113–115). The type of pyrometer consisting of a number of thermocouples of different thicknesses is examined with a view to establishing a system whereby the true temperature of a flowing gas can be ascertained by a single reading. The conditions having been established, the practical difficulties of design are considered and means suggested for minimising them. The case of a resistance thermometer for measuring gas temperatures is then considered and the proposed circuit diagram for such an instrument described.

On the Effect of Colour-Sensitivity on Temperature Readings with Bioptix Pyrometers. S. Fornander. (Jernkontorets Annaler, 1941, vol. 125, No. 2, pp. 67–79). (In Swedish). The author reviews previous reports on the application of the Bioptix pyrometer both in the laboratory and on industrial plant. He then describes his own investigation, in which six observers whose colour-sensitivities were tested took readings of a tungsten lamp at constant temperature, each observer using four Bioptix pyrometers in turn. It was found that the same observer obtained appreciably different readings with different instruments, and that the differences between different observers' readings with the same instrument varied considerably. One of the observers whose colour-sensitivity to green was very slight could not determine temperatures to within 100° C. with this instrument.

HEAT TREATMENT

Hardening Small Parts Aided by Unusual Furnace. (Steel, 1941, vol. 108, Apr. 28, pp. 70–71). **Case Hardening Small Parts in a New Type of Continuous Gas Furnace.** (Iron Age, 1941, vol. 147, May, pp. 44–45). An illustrated description is given of a gas-fired furnace for case-hardening small parts used in automobile construction. The furnace is 27 ft. 6 in. long and is large enough to take 56 trays 12 in. × 18 in. in two rows ; these are moved by a pusher mechanism at the charging end. The working temperature is 1500–1525° F., the heat reaching the charge from radiant tubes 5 in. in dia. The carburising gas is a mixture of a prepared gas with city gas, propane and ammonia. At the discharge end there are double doors, and as a pair of trays is pushed in at the charging end, a pair pushed out on to a quenching platform between the double doors. The inner door is closed and the platform is automatically lowered into the oil quenching tank. The movement of the platform is controlled by an electric clock connected with the pusher mechanism.

Carburising with Gaseous Media. F. Collins. (Metallurgia, 1941, vol. 24, May, pp. 18–21). The author reviews the history, basic principles and development on an industrial scale of gas carburising, and compares the gas- and pack-carburising processes. He also gives some information on the depth of case produced on low-carbon steel by introducing oils (*e.g.*, petroleum, Diesel fuel oil, petrol, benzene and linseed oil) drop by drop into a hot retort.

Gas Carburising. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, June, pp. 48–50). Some of the advantages of gas carburising as compared with pack and salt-bath carburising are pointed out, and the construction of a batch-type furnace for gas carburising charges of 50–150 lb. is described.

Carburization and Decarburization. F. A. Loche. (Iron Age, 1941, vol. 147, June 12, pp. 41–44). The author discusses the use of gases for carburising steel, and comes to the following conclusions as to the factors affecting the amount of carbon in the surface of steel at elevated temperatures : (1) Carbon monoxide and methane are carburising gases, whilst oxygen, moist hydrogen, steam and carbon dioxide are decarburising gases ; (2) if steam or carbon dioxide is present in furnace gases, then, to prevent any decarburisation, there should also be present either ten times as much hydrogen as there is steam, or ten times as much carbon monoxide as there is carbon dioxide ; (3) it is possible to decarburise without scaling ; (4) when the products of combustion are in contact with the steel it is better to work with an oxidising atmosphere and allow the decarburised layer to form scale, which is subsequently removed by pickling, than to work with a reducing atmosphere ; (5) if dissociated ammonia is used, the gases must be absolutely dry and a liquid-

sealed retort must be employed ; (6) when the atmosphere consists of partially burnt fuel gases the sealing need not be so efficient as with cracked ammonia ; and (7) if pure nitrogen is applied, large quantities must be used, as it only prevents decarburisation by any oxygen present by a mechanical flushing action.

Heat Treating Aircraft Gears. J. L. Buehler. (Iron Age, 1941, vol. 147, June 26, pp. 39–42). The author discusses the precautions to be taken in the heat treatment of alloy steel gears for aircraft engines. In his own experience he has found that only gas-carburising is satisfactory. He describes and illustrates a special container in which a number of gears can be placed for heat treatment. While in the furnace the carburising and slightly reducing atmosphere can circulate through it, and when the container is lifted out of the furnace and immersed in the quenching oil it carries sufficient gas with it to prevent the air from scaling or even discolouring the gears.

Distortion in Casehardening. I. Stewart. (Machine Shop Magazine, 1941, vol. 2, July, pp. 94–99). The author makes some practical suggestions as to means of preventing the distortion of parts during the case-hardening process. One of these is that the shape of the container should be similar to that of the part ; for example, pinions with a large centre hole should be packed in annular containers, for this not only ensures even heating and cooling, but also effects a considerable saving in the amount of compound used over a period. The technique of quenching in a die to prevent distortion is described.

An Improved Method of Determining the Case Depth of Carburised Work. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, June, pp. 51–52). A description is given of a simple method of revealing the line of demarcation between the case and core of a case-hardened part. The carburised test-piece or component is heated, quenched and broken in the ordinary way to reveal the fracture. The broken part is then gently heated in a flame from a gas torch or Bunsen burner, care being taken to concentrate the heat some distance away from the fracture. The part is examined from time to time, and as soon as the first positive change in colour becomes visible, it is quenched in water. On allowing the moisture to evaporate, the case and the core are found to stand out in colourful contrast.

Flame Hardening Standardization. A. L. Hartley. (Iron Age, 1940, vol. 146, Oct. 17, pp. 25–34 ; Oct. 24, pp. 34–38 ; Oct: 31, pp. 34–43 ; Nov. 14, pp. 48–52) In this series of articles the author describes an investigation of the flame-hardening process as applied to cast iron and steel, his object being to demonstrate the possibility of standardising the technique so that reproducible results can be obtained. In the first part he examines the hardenability of the following types of cast iron : (1) Ordinary cast iron containing total carbon 2·91% ; (2) one containing total carbon 2·92%, nickel 0·81% and chromium 0·17% ; and (3) one containing total carbon 3·20%,

molybdenum 0·32% and chromium 0·18%. The results are shown in a chart in which micrographs of each of the irons quenched in oil from seven different temperatures in the range 1425–1700° F., and their hardness values can readily be compared. The flame-hardening torch used in subsequent experiments is described in this part. In the second part the flame-hardening technique which was developed for producing a hard case $\frac{3}{32}$ in. to $\frac{5}{32}$ in. deep on the flat surface of a chromium-molybdenum cast iron is described, and tentative standards are established with regard to the equipment, the distance between the surface of the metal and the burner nozzle, and the rate of travel over the surface. The technique for flame-hardening two adjacent surfaces forming an angle of 90° is discussed, and the hardness obtained at different depths are correlated with the microstructure. In the concluding part the author considers the distortion caused by flame-hardening treatment and describes how certain parts are flame-hardened on both sides so that the stresses produced are balanced and no distortion is caused. Some specially designed tips incorporating both the burners and the quenching jets are also described in this part.

Flame Hardening Cast Iron Bearing Rings. J. L. Foster. (Metal Progress, 1941, vol. 39, Apr., pp. 438–439). The author describes the flame-hardening of cast-iron bearing rings $9\frac{3}{4}$ in. in dia. (*See* p. 10 A).

Surface Hardening by Induction. H. B. Osborn, jun. (Electrochemical Society, 1941, Apr., Preprint No. 24). After an explanation of the principles applied in induction hardening and of the metallurgical effects produced in the steel by the very rapid heating, the author describes an investigation of the rate at which carbide solution takes place in specimens of a 0·5% carbon steel heated by the induction method. Calculations from the data obtained show that the surface of many of the test bars were actually above the lower critical point for extremely short periods, the time in many cases being less than 1·0 sec., and in a few cases 0·2–0·3 sec. The hardness obtained and the lack of free ferrite and carbide in the microstructure proved that complete carbide solution and homogeneity were attained in each case. While periods of 0·2 and 0·3 sec. for complete carbide solution are much shorter than any period previously published in technical literature, the author demonstrates by calculations that it is possible to have complete carbide solution in the critical temperature in immeasurably short periods of time. In any case, induction-hardening equipment is now being used on a production scale with which complete carbide solution is obtained by a heating and quenching cycle taking less than 2 sec. In the concluding part of the paper a number of induction-hardening units for the surface hardening of crankshafts, camshafts and track pins are described and illustrated.

Surface Hardening by Induction. (Metallurgia, 1941, vol. 24, June, pp. 61–64). An account is given of some investigations of the

depth and distribution of hardness obtained in steel by the induction process of hardening, the information given being based on the paper by Osborn. (*See* preceding abstract).

Controlled Atmosphere Generators ; Recent Advances in Equipment. E. E. Slowter. (Metal Progress, 1941, vol. 39, May, pp. 560–566, 628). The author describes a number of gas-producing plants for producing protective atmospheres for the heat treatment of steel. These include : (*a*) A nitrogen generator with a purifier and solvent regenerator. (*b*) A pit-furnace generator for producing a protective gas consisting essentially of carbon monoxide and nitrogen ; in this equipment the air, or other gas, is passed over carbon which is at the same temperature as the steel being treated, the principle applied being that an atmosphere in equilibrium with carbon at a given temperature will be non-decarburising and non-oxidising to any steel at the same temperature. (*c*) A unit using producer gas from charcoal and enriched with benzol, or ammonia or both. (*d*) A generator producing carbon monoxide, hydrogen and nitrogen from the partial combustion of natural gas and air. (*e*) A unit consisting of a petrol engine, the exhaust gases of which are cooled in a condenser, and a receiver for additional water condensation with a large capacity to smooth out the pulsations ; the gas from the receiver is usually passed direct to the heat-treatment furnace. The engine for small units is air-cooled, and the hourly output varies from 150 to 750 cu. ft. of prepared gas ; it is desirable that the engine be fairly well loaded, so as to make the unit more efficient and to provide a means of controlling the speed.

Possibilities of Modern Furnaces and their Atmospheres in the Bright Heat Treatment of Steel. (Sheet Metal Industries, 1941, vol. 15, June, pp. 745–753). In the concluding part of this paper (*see* p. 11 A) the practical application of the reactions dealt with in the first part are considered with particular reference to the maximum quantities of carbon dioxide, water vapour and hydrogen which can be permitted in furnace atmospheres for the bright annealing of steel.

Precise Heating-Cooling Cycles Afforded by New Batch-Type Annealing Furnace. J. J. B. Rutherford and N. Hamilton. (Steel, 1941, vol. 108, May 26, pp. 88, 89, 95, 96). The authors give a detailed and illustrated description of a pair of batch-type furnaces for the annealing of seamless alloy steel tubes. The furnaces are fired with natural gas and the heating chambers are 6 ft. 9 in. wide, 4 ft. high and 31 ft. long, each having a capacity of 16 tons of tubes. Accurate control of the furnace atmosphere enables it to be adjusted from strongly reducing to strongly oxidising ; as a rule the setting is such as to produce slightly oxidising conditions in order to prevent decarburisation and to produce a scale that can be easily removed. The hot gases are circulated through the charge at high velocity by a fan which ensures rapid and uniform heating of the whole charge.

Electric Semi-Continuous Controlled Atmosphere Furnaces. E. Hague. (Metallurgia, 1941, vol. 24, May, pp. 25–26). The author

describes, with illustrations, a semi-continuous electrically heated furnace for the heat treatment of small parts on trays. These furnaces have an overall length of about 20 ft. and an output of about 400 lb. per hr. Brief particulars are also given of a unit for the supply of partially burnt town gas as a protective atmosphere for the above furnace.

Controlled Gas Guards Steel. J. R. Gier. (Machinist, 1941, vol. 85, July 12, pp. 284–285). The author explains the necessity of preventing the oxidation and decarburisation of steel in heat-treatment furnaces and describes the characteristics of protective atmospheres with special reference to "Endogas," which is a mixture of carbon monoxide, hydrogen, nitrogen and a little methane, formed by the endothermic reaction of a hydrocarbon fuel and air.

Heat Treating Facilitated by Mechanical Handling. A. V. Dennison and F. A. Westbrook. (Iron Age, 1941, vol. 147, May 22, pp. 56–58). The authors describe and illustrate the mechanical handling equipment at an American heat-treatment shop for large and small parts. Small parts are discharged from a carburising furnace on to an endless belt conveyor on which they are spread out and cooled in the air. Overhead monorail cranes are used for heavier parts.

Heat Treatment of Steel Castings—Early History. J. H. Hall. (Metals and Alloys, 1941, vol. 13, May, pp. 563–569). The author gives an account of his experiences with the heat treatment of steel castings in some American foundries and metallurgical laboratories from about 1905 onwards. His main problem was the production of a fine structure in both large and small castings.

Bethlehem Steel Increases Facilities for Electric Heat Treating of Bars. (Industrial Heating, 1941, vol. 8, Mar., pp. 245–252). The recently reorganised heat-treatment department for bars at the works of the Bethlehem Steel Company are described and illustrated. (*See* p. 48 A).

A Gas-Fired Installation for the Heat Treatment of Forgings. (Machinery, 1941, vol. 53, June 5, pp. 271–273). **Heat-Treatment Plant.** (Automobile Engineer, 1941, vol. 31, May, pp. 162–164). **Production Heat Treatment of Forgings.** (Mechanical World, 1941, vol. 109, May 30, p. 371). An illustrated description is given of a new gas-fired heat-treatment plant for large quantities of small forgings. (*See* p. 12 A).

Hardening Drill Steel with the Radiation-Type Thermocouple. C. G. Kemsley. (The Canadian Mining and Metallurgical Bulletin, 1941, May, pp. 197–202). The author describes a small heat-treatment installation at a Canadian mine. This is used for the hardening of molybdenum-steel drills. The method of temperature control is of interest as a foil-type thermocouple enclosed in a vacuum tube is used. The heated end of the drill is placed in a special rest, which holds it at a fixed distance from the vacuum tube. The thermocouple is connected to a high-sensitivity reflect-

ing galvanometer, and it has been found that with this equipment an unskilled operator can take accurate temperature readings and quench the drill when the correct temperature is reached, thus producing drills of consistent hardness.

Chromium Steel for Ball Bearings ; Inspection and Heat Treatment. A. S. Jameson. (Metal Progress, 1941, vol. 39, May, pp. 567–573). The author describes the manufacture and necessary properties of low-chromium steels for the races and balls of bearings under 6 in. in dia., with particular reference to the heat treatment.

A Note on the Theory of Quenching. J. H. Awberry. (Iron and Steel Institute, 1941, this Journal, Section I.). The heat transfer to a fluid from the plane surface of a solid follows different laws according to the temperature of the surface. If this latter temperature is sufficiently far above the boiling point of the fluid, there is a regime in which a sheath of vapour forms between the solid and the fluid. It is shown that, during this regime, the heat loss H per unit area per second is $B(T_B - T_0)$ $(k_l^2 \alpha g c/\nu)^{\frac{1}{4}}$, where B is a constant, approximately 0·0015, if thermal quantities are measured in calories. The other symbols have the following meanings : T_B, boiling point of the fluid ; T_0, temperature of the mass of the fluid ; k_l, thermal conductivity of the fluid at the temperature $T' = (T_B + T_0)/2$; α, coefficient of cubic expansion of the fluid at temperature T' ; g, acceleration due to gravity ; c specific heat of fluid per unit volume at temperature $T' = (T_B + T_0)/2$; ν, kinematic viscosity of fluid at temperature T'.

WELDING AND CUTTING

(Continued from pp. 83 A–85 A)

Oxy-Acetylene Welding of Steel Pipe Butt Welds. H. Harris. (Journal of the West of Scotland Iron and Steel Institute, 1940–41, vol. 48, Part IV., pp. 47–57). The present paper is supplementary to a report of an earlier investigation by the author in collaboration with J. E. Jones and A. L. Skinner (*see* Journ. I. and S.I., 1941, No. I., p. 59 A) and it deals with the making of butt welds by the autogenous process in steel pipes of all sizes used in steam generation and distribution. To illustrate the effects of welding with strongly and slightly carburising flames and with neutral and oxidising flames, four micrographs are presented and the appearance of the metal is related to the results of bend tests on specimens welded with these four types of flame. These experiments show how important it is to have welding equipment which will maintain a constant flame condition having the required characteristics. The difference between the composition of a number of welding rods and that of the deposited weld metal is shown in tables. With

very low carbon steel rods it is easy to obtain oxidised weld metal, so that it has now become the practice to use rods relatively high in manganese and silicon, for these two elements are preferentially oxidised, and leave a deposit of good-quality deoxidised steel.

The Principles and Application of " Unionmelt " Welding.   A. Hägglund. (Teknisk Tidskrift, 1941, vol. 71, Apr. 19, Mekanik, pp. 33–42). (In Swedish). The author gives a detailed account of the " Unionmelt " process of electric welding, explains the principles involved and describes, with many illustrations, the equipment used and numerous examples of welds made by this process. (*See* Journ. I. and S.I., 1939, No. I., p. 284 A).

Welding Different Steels. (Metal Treatment, 1941, vol. 7, Summer Issue, pp. 58–63). In this article some of the recent American technical publications on the factors which influence the hardening of the metal in the vicinity of welds in carbon and low-alloy steels are reviewed.

Welded Construction of Blast-Furnace Stoves. H. C. Boardman. (Iron and Steel Engineer, 1941, vol. 18, May, pp. 44–50). The author gives a detailed account of the procedure adopted for welding the shell plates and dome covers of two butt-welded blast-furnace stoves 119 ft. high and 21 ft. in dia.

Oxy-Acetylene Machine Cutting of Selected Types of High Tensile Structural Steels. L. C. Percival. (Transactions of the Institute of Welding, 1941, vol. 4, July, pp. 114–140). The author reports on an investigation the object of which was to determine whether the operation of oxy-acetylene machine cutting had any detrimental effects on the mechanical properties of the low-alloy high-tensile structural steels covered by British Standard 548 (1934). Eleven steels $\frac{1}{2}$ in. and 1 in. in thickness were selected, and specimens were oxy-acetylene machine cut under controlled conditions. The results of tensile, cold-bend and hardness tests on these and on specimens cut with machine tools are given in numerous tables, and data sheets are also presented showing the cutting speeds and the consumption and pressure of the gases. Adopting as a criterion a maximum diamond pyramid hardness of 350, steels to the following four analyses were selected as being just as suitable for oxy-acetylene cutting (without special precautions) as ordinary mild steel : (*a*) Chromium 0·82%, copper 0·40%, silicon 0·457% and phosphorus 0·149% ; (*b*) chromium 0·45%, manganese 0·55%, silicon 0·78% and zirconium 0·10% ; (*c*) copper 1·13%, nickel 1·31% and molybdenum 0·10% ; and (*d*) carbon 0·09%, copper 0·95% and nickel 1·96%. A certain standard heating-flame setting was found to be satisfactory for each thickness of plate irrespective of the type of steel. No difficulty was encountered in the cutting of any of the steels.

The Weldability of Steel. Experience and Tests. R. Kühnel. (Stahl und Eisen, 1940, vol. 60, May 2, pp. 381–390 ; May 9, pp. 405–409). After reviewing the present state of the development of welding rods and of steel of good welding quality, the author

presents the results of tests on specimens of steel St 52 taken from parts of the welded steel bridge at the Zoo Station in Berlin and one at Rüdersdorf, as well as steel from the Hasselt bridge in Belgium, at all of which serious failures had taken place. These results are discussed and compared with the results of bend and hardness tests on specimens of mild steel, steel St 37 and a medium-hard steel with a tensile strength of 50 kg. per sq. mm. welded in various ways.

Investigation of Crack Formation in Welded Structures of Steel St 52. W. Grosse. (Stahl und Eisen, 1940, vol. 60, May 23, pp. 441–453). After giving a brief description of the design of the welded steel bridges at the Zoo Station in Berlin and at Rüdersdorf in the girders of which failures occurred, the author gives an account of an investigation of the weldability of the German high-tensile steel St 52 of which these bridges were made. It was found that this steel was particularly sensitive after welding to the effects of externally applied stresses. If the steel were produced in the fine-grained state, this did not obviate the danger of crack formation in the hardened zones. A reduction in the carbon and manganese contents reduced the danger of crack formation, but this also reduced the elastic limit and tensile strength of the steel. Further investigations are proceeding regarding the amount by which the elastic limit may be reduced. In the meantime it is recommended that a softer and less sensitive steel be selected if the structure must be welded, otherwise riveting must be resorted to.

Comparative Weld-Bend and Impact Tests on Steel St 52. R. Wasmuht and C. Salzmann. (Stahl und Eisen, 1940, vol. 60, May 23, pp. 453–456). The authors report on an investigation the purpose of which was to ascertain whether a less time-consuming test than the bend test on weld metal, giving reliable results, could be devised for testing the weldability of high-tensile steels. The bend test on weld metal has been described earlier. (*See* Journ. I. and S.I., 1940, No. I., p. 244 A) The results of numerous hardness and impact tests are tabulated, and it is shown that, whilst certain conclusions can be drawn regarding the weldability of steels from the results of impact tests on sharply notched specimens, this form of testing cannot fully replace the bend test on weld metal. The specimens in this investigation were all of German high-tensile steel St 52.

The Effect of Heat Treatment on the Strength Properties and Welds of Structural Steel St 52. K. L. Zeyen. (Stahl und Eisen, 1940, vol. 60, May 23, pp. 456–461). The author gives an account of an investigation of the effect of previous and subsequent heat treatment on the strength of butt welds in structural steel St 52. Tensile, tensile-fatigue, bending-fatigue and impact tests were made on welded specimens of $\frac{1}{2}$-in. plate. The results are given in numerous tables and graphs, and it is shown that either preheating, or subsequent heating to 250° C., or subsequent annealing at 550° C.

had a slight favourable effect on the tensile, bending-fatigue and impact test results; the slight detrimental effect on the tensile-fatigue test results produced by normalising was so small as to be without practical significance.

PROPERTIES AND TESTS

Mechanical Properties of Steel. J. C. Millson. (American Society for Metals : Canadian Metals and Metallurgical Industries, 1941, vol. 4, May, pp. 110–114). The author explains in general terms the factors affecting the tensile strength, elongation and hardness of steel, and how these can be controlled by hot-working and heat treatment.

Impact and Hardness Tests ; Notes on Their Practical Use. G. T. Williams. (Metal Progress, 1941, vol. 39, May, pp. 585–591). The author describes the Charpy and Izod impact tests and the shape of the specimens used for them, and the Brinell, Rockwell and diamond-pyramid hardness tests, and discusses the significance of the values obtained by them.

Some Fundamentals of the Flow and Rupture of Metals. G. Sachs. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1335 : Metals Technology, 1941, vol. 8, June). The author surveys the present state of knowledge on the flow and rupture of metals. He considers in turn : (a) The effect of various types of stresses such as tension, compression and shear and combinations of these on flow; (b) the effect of hydrostatic pressures on plastic flow ; (c) the effect of stress state on ductility ; (d) stress and strain of single crystals and of polycrystalline aggregates ; (e) the strain-hardening of metals ; (f) the effect of tool contact and friction on plastic flow; and (g) speed and impact effects. In conclusion he points out that, whilst the complex theory of elasticity is based on a number of assumptions incorporated in Hooke's law and on a knowledge of a few properties of the materials, plasticity and rupture depend on numerous fundamental factors and many specific properties of the metals.

Flow of Solid Metals from the Standpoint of the Chemical-Rate Theory. W. Kauzmann. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1301 : Metals Technology, 1941, vol. 8, June). The author outlines Eyring's general statistical theory of shear rates and applies this in a consideration of creep-test data. From the values of the constants in Eyring's equation required to fit the data, it is shown that it is very probable that creep in metals usually occurs by the shear of rather large blocks of material in the unit molecular process, rather

than by the movement of single atoms past one another, as in diffusion. This is seen to be in good agreement with existing ideas on the flow of crystals by means of dislocations. Such problems as why some metals are softer than others, the effects of impurities on hardness, the softness of single crystals and the rôle of self-diffusion in creep are considered in the light of the theory of the rate of chemical reactions.

Selection of Steels as Affected by Endurance Limit. G. T. Williams. (Metal Progress, 1941, vol. 39, Apr., pp. 464–468, 508). In this general discussion of fatigue testing the author gives examples of the effect of different shapes of groove, surface condition, heat treatment and decarburisation on the endurance limit of steel.

Fatigue Tests of Welded Joints in Structural Steel Plates. W. M. Wilson, W. H. Bruckner, J. V. Coombe and R. A. Wilde. (Illinois University, 1941, Engineering Experimental Station Bulletin Series No. 327). The Welding Research Committee of the Engineering Foundation organised a committee (known as Committee F) to plan and carry out an investigation of the fatigue strength of welded joints, and the present paper is a progress report on the results on butt and fillet welds in steel plates. The conclusions reached include the following : (1) With butt-welded specimens the fatigue strengths of stress-relieved and of non-stress-relieved joints were approximately equal, and this was true whether or not any surplus weld metal was removed ; (2) specimens from which the surplus weld metal was machined off flush with the base-plate had the same fatigue strength as plates without welds but with the mill-scale on ; (3) removing surplus weld metal with a portable grinder lowered the fatigue strength of a butt-welded joint slightly as compared with that of joints from which the surplus weld metal was removed by machining ; and (4) removing surplus weld metal by machining and then polishing caused the fatigue strength to be slightly higher than that of specimens with the mill-scale on. Detailed results of the tests are given in numerous tables.

Magnetic Powder Pictures and the Fatigue Endurance of Spiral Springs. M. Hempel. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 479–487). This paper is an abridged account of an investigation of the life of spiral springs with and without surface defects carried out by the author and A. Pomp, a full account of which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 4, pp. 35–56. (See Journ. I. and S.I., 1940, No. I., p. 298 A).

Hardenability Tests ; Correlation Each to Each. W. E. Jominy. (Metal Progress, 1941, vol. 39, Apr., pp. 447–451). The author describes how the hardenability of steel bars can be determined by various tests, such as those of Klain and Lorig, Shepherd, Grossmann, Scott and by his own end-quenching test, and discusses the applicability of these tests for steels of different types and the

degree of agreement attained when comparing the hardness data obtained by them on specimens of the same steel.

Ageing Phenomena in Steel. J. White. (Metal Treatment, 1941, vol. 7, Summer Issue, pp. 64–70). The author gives a brief account of the results of recent investigations into the phenomenon of ageing in steels. He reviews critically the conclusions of several American, German and English metallurgists on the influence of carbon, nitrogen and oxygen on the ageing of steels, and discusses the relation between ageing after quenching and after straining.

Brake Drums. O. Smalley. (Society of Automotive Engineers : Foundry Trade Journal, 1941, vol. 64, June 12, pp. 387–388, 386 ; June 19, pp. 405–407 ; June 26, pp. 423–424, 427 ; vol. 65, July 3, pp. 6–7). The author points out the difficulty of discovering the causes of the wear and scoring of cast-iron brake drums, and describes some dynamometer tests on the following types of brake-drum material : (1) Standard " D " Meehanite ; (2) a molybdenum cast iron ; (3) a high-duty cast iron ; and (4) a nickel-chromium cast iron. From the results of these tests deductions are made as to the most suitable metal to use for brake drums of tractors, trailers and omnibuses.

Transformers Simplified by New Steel. (Iron Age, 1941, vol. 147, May 15, pp. 52–54). A brief description is given of the process of manufacturing " Hipersil " transformer steel, a steel containing 2·90–3·30% of silicon and less than 0·02% of carbon. It is claimed that this material has one-third greater magnetic flux carrying capacity than the conventional silicon transformer steels.

New Steel Simplifies Transformers. H. V. Putnam. (Blast Furnace and Steel Plant, 1941, vol. 29, May, pp. 533–534). The author discusses the magnetic properties of a new transformer steel called " Hipersil." (*See* preceding abstract).

Second Report on the Electrical Sheet with Special Reference to Transformer Sheets. M. Nakajima. (Tetsu to Hagane, 1941, vol. 27, Mar. 25, pp. 167–183). (In Japanese). The author describes the development of the manufacture in Europe, the United States and Japan of special steel for transformers, and discusses the electrical properties of this class of steel.

Coefficients of Expansion. (Metallurgist, 1941, vol. 13, June, pp. 17–18). Some of the results obtained by Esser and Eusterbrock in their determinations of the coefficients of expansion of metals using an improved form of dilatometer are presented. This dilatometer was designed to avoid what were regarded as possible sources of error in the Chevenard dilatometer. The values of the coefficients of expansion of carbonyl iron, electrolytic iron with 0·004% and with 0·01% of carbon, and of iron-carbon alloys made from carbonyl iron were determined at intervals of 50° or less over the range 18–1000° C. The mean coefficient of expansion of carbonyl iron and of the electrolytic irons is very similar from 18° to 100° C., but the true coefficient, which in all cases attains a maximum at 525° C.,

reaches a higher value in the carbonyl iron than in the other two. Above that temperature the value falls to a sharp minimum at Ac_2 and then rises again. The mean coefficient of expansion of the iron-carbon alloys between 18° and 100° C. diminishes with increase in carbon content. The change of length measured by the vertical distance between the α-iron and γ-iron lines in the dilatometric record decreases continuously from about 0·37% to about 0·15% of the length at 18° C. with increase in carbon content.

Equations for the Time-Elongation Curves in Creep Tests. F. Bleilöb. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 489–496). In this mathematical discussion the author develops formulæ for the interpretation of the results of creep tests, in particular he works out a basic formula which expresses the influence of both time and load at constant temperature.

Tensile Properties of Iron at Raised Temperatures. (Metallurgist, 1941, vol. 13, June, pp. 22–24). An abridged English translation is presented of a recent paper by Eilender, Cornelius and Menzen on the influence of impurities and of the minor constituents of iron and of dead-mild steel on the tensile properties of the material in the blue-brittle range. (*See* p. 28 A).

Possible Substitutes for Nickel Steels. (American Iron and Steel Institute, May, 1941, Contributions to the Metallurgy of Steel— No. 1). In this publication particulars are given, chiefly in the form of tables of analyses and diagrams comparing tensile, impact and hardness properties, of various steels which can be substituted for nickel steels. Part I. is introductory in character ; in it some of the limitations of the substitute steels are explained and it is stated that the report deals only with constructional steels containing not more than the following amounts of the given elements : chromium 1·50%, nickel 5·25%, molybdenum 0·75%, manganese 2·00%, silicon 2·00% and vanadium 0·20%. Part II. covers the carburising steels. Part III. deals with substitutes for nickel steels of the deep-hardening type. In Part IV. some low-carbon alloy steels are listed which have low hardness values in the as-rolled, normalised or quenched and tempered states. In conclusion, Part V. gives some standard methods of sampling for making check analyses and tables of the standard variations above or below the specified range of chemical analysis of open-hearth and electric-furnace steels.

On the Study of the Substitute for Nickel-Chromium Steels. S. Nishigori and C. Asada. (Tetsu to Hagane, 1941, vol. 27, Mar. 25, pp. 151–166). (In Japanese). The authors report on an investigation of the properties of some alloy steels with composition within the following limits, carbon 0·25–0·50%, chromium 0·8–2·0% and molybdenum 0·5% max. and their suitability as substitutes for low-nickel, low-chromium steels.

Molybdenum Steels in Aircraft Construction. (Climax Molybdenum Co., Pamphlet, 1941). Full particulars are given of the

heat treatment and the physical and welding properties of steels S.A.E. $X4130$ and $X4140$, both containing chromium $0.80–1.10\%$ and molybdenum $0.15–0.25\%$, the former with carbon $0.25–0.35\%$ and the latter with carbon $0.35–0.45\%$.

Comparison of Manganese Steel with Carbon Steel for Detachable-Bit Drill Rods. W. G. Agnew. (United States Bureau of Mines, 1941, Apr., Report of Investigations 3566). The author reports on the results of tests to ascertain the relative durability of manganese steel and carbon steel drill rods for use with detachable bits. The carbon and manganese steels contained carbon 0.79% and 0.34%, and manganese 0.23% and 1.57% respectively. The results indicated that the manganese steel rods lasted about 50% longer than the carbon steel rods, and that failure in the former was mainly due to breakage of the shanks. The tests established the need for further research on fabrication and heat treatment of drill shanks made of both these types of steel.

The Working of Tool and Die Steels. (Machinist, 1941, vol. 85, June 28, pp. 243–258). In this comprehensive article the composition, properties and applications of tool and die steels are dealt with under the following headings : (1) Alloying elements ; (2) selecting a steel ; (3) forging and heat treatment ; and (4) machining tool and die steels. Several tables of analyses and properties are presented.

The Free-Machining Stainless Steels. S. P. Watkins. (Metal Progress, 1941, vol. 39, Apr., pp. 452–458, 500). The author discusses the properties of six types of free-machining stainless steels. These types are the low-carbon and high-carbon $12–14\%$ chromium steels, the low-carbon and high-carbon $16–18\%$ chromium steels and the $18/8$ steels containing either about 0.30% of sulphur and 0.35% of molybdenum, or about 0.30% of selenium. Many tables, curves, micrographs and drawings are presented relative to the analyses, physical properties, weldability, microstructure and transformation temperatures of these steels, and a special section deals with the turning speeds and contours of tools and drills for machining them.

The Care and Maintenance of Winding Ropes and Attachments, as Practised at the South Mine, Broken Hill, N.S.W. E. K. Goninan and M. W. Howell. (Proceedings of the Australian Institute of Mining and Metallurgy, 1940, No. 119, Part II., pp. 525–545). The author describes the construction of the various types of wire ropes used for winding in Australian mines and the procedure for inspection, lubrication and maintenance of these ropes adopted at the South Mine, Broken Hill, New South Wales.

War Emergency British Standard Specification for High Tensile (Fusion Welding Quality) Structural Steel for Bridges, etc., and General Building Construction. (British Standards Institution No. 968–1941). Recent investigations by the Institute of Welding on the weldability of the high-tensile steels described in British

Standard No. 548 have shown that unless certain precautions are taken difficulties due to hardening at the weld boundaries may arise. Special welding-quality high-tensile steels are now available with maximum carbon contents considerably lower than the 0·30% allowed in the above standard specification. The present Standard relates to steels of this type with carbon limited to 0·23% max., and they are designated " high tensile (fusion welding quality) steels," abbreviated to " H. T. W. Steels." The material specified is not suitable for forge or smith welding.

War Emergency British Standard Schedule of Wrought Steels in the Form of Bars, Billets, Light Forgings and Stampings up to 6 in. Ruling Section for General Engineering Purposes. (British Standard Schedule 970–1941).

British National Specifications for Cast Iron. J. G. Pearce. (Institute of British Foundrymen Conference, July, 1941, Paper No. 733). The author discusses the value of the tests specified for cast iron in British Standards 321 and 786.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 98 A–101 A)

Practical Metallography of the Stainless Steels. S. P. Watkins. (Metals and Alloys, 1941, vol. 13, Jan., pp. 30–35 ; Feb., pp. 162–168 ; Mar., pp. 288–293 ; Apr., pp. 431–435). The author describes the conventional methods of etching stainless steel for microscopical examination and gives tables of data concerning the etching reagents used for immersion etching and electrolytic etching. He then gives an account of the effect of alloy additions, especially chromium and nickel, on the properties of stainless steel. He considers the phase diagrams of stainless steels of various compositions and reproduces numerous micrographs. In conclusion he discusses the heat-treatment sensitivity of various types of stainless steels, dividing them into three groups, viz. : (1) Martensitic, hardenable, straight chromium steels ; (2) ferritic, non-hardenable, straight chromium steels ; and (3) austenitic chromium-nickel steels, hardenable by cold-work only.

Ultrasonics—A New Metallurgical Tool. C. M. Cosman. (Iron Age, 1941, vol. 147, May 15, pp. 48–50). The author states that ultrasonic generators are now commercially available in the United States, and quotes briefly examples of the work of a number of investigators who have shown that vibrations at more than 17,000 cycles per sec. have been successfully applied for locating defects in metal, degassing molten metal, accelerating hardening treatment and for dispersing one metal in another, e.g., lead in aluminium.

The Non-Destructive Testing of Castings with the Aid of Super-sonics. F. Schroeder. (Giesserei, 1940, vol. 27, May 17, pp.

186–188). The author describes some methods of producing super-sonic waves with particular reference to one which is based on a reversed piezo-electric effect. In this apparatus the wave generator consists of a thin quarz plate cut from a larger piece in such a manner that its two principal parallel faces are perpendicular to one of the three polar axes, and so that the second axis is parallel to the optical axis. If the plate is placed between two excitation electrodes in such a position that the field of the excitation impulses is in line with one of the axes of the plates, two types of oscillations can be produced. These are the transverse or " thickness " oscillations producing supersonic waves on the principal surfaces at frequencies up to 50×10^6 cycles per sec., and longitudinal oscillations at frequencies up to about 300,000 cycles per sec. Schematic diagrams of the generator alone and of the generator applied to a cast iron roll with an optical device for the reception of the waves at the other end of the roll are given.

Surface Finish and Structure. J. Wulff. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1318 : Metals Technology, 1941, vol. 8, June). The author discusses the results of an investigation in which electron-diffraction photographs were taken of successively etched 18/8 stainless-steel surfaces in order to ascertain the depth and nature of the deforma-tion induced by such finishing processes as cold-rolling, dry and wet grinding, lapping, honing, sanding, super-finishing and metal-lographic polishing. For surfaces of approximately the same " root-mean-square " profile, the pressure was found to influence the depth of deformation, the rate of abrasion, the temperature, and thus the nature of the deformation. The results indicated that during fine dry grinding the temperature at the point of contact might be higher than $600°$ C. and that of a layer of metal $6\cdot3 \times 10^{-4}$ cm. below this point might rise above $200°$ C. In material that had been cold-rolled there was no indication that the temperature exceeded $200°$ C. With surfaces that had undergone superfinishing, lapping and metallographic polishing, the depths of deformation did not exceed $1\cdot5 \times 10^{-5}$ cm. and the temperature did not exceed $200°$ C.

Inspection of Aircraft Components. R. C. Woods and T. N. Nolan. (Iron Age, 1941, vol. 147, June 12, pp. 46–49). The authors give a brief description of the application of X-ray equip-ment in an American aircraft factory for the examination of welds, of the meshing of gears and of plastic materials.

The Possibilities of Fluorescent-Screen Photography for the X-Ray Investigation of Coarse Structures. W. Schmitz and W. Wiebe. (Stahl und Eisen, 1940, vol. 60, May 16, pp. 423–426). The authors examine the possibility of applying fluorescent-screen photography for the testing of materials and make practical proposals for carrying this out. They reproduce and compare some pictures of fine-mesh steel wire netting, weld metal and a wireless valve taken by direct

X-rays and by the fluorescent-screen technique. The ability to detect defects is slightly less with the latter process, but it has the advantage, especially when using a camera producing small pictures, of a smaller film consumption and of requiring less time than the direct X-ray process.

Corrections to Published Analyses of Meteorites. E. P. Henderson. (American Journal of Science, 1941, vol. 239, June, pp. 407–411). As some of the published analyses of iron meteorites give nickel contents which are inconsistent with their metallurgical structures, new analyses of some of the meteorites in the United States and in Mexico have been made. The author presents the results of a number of these analyses and comments on the difference in the nickel contents which were found.

Recommended Method for the Determination of Grain Sizes in Steel in Report No. 6 of the 19th Sectional Committee of the Japan Society for the Promotion of Scientific Research. K. Tawara. (Tetsu to Hagane, 1941, vol. 27, Mar. 25, pp. 145–149). (In Japanese). The Sectional Committee of the Japan Society for the Promotion of Scientific Research have recommended a method of determining the grain-size of steel. The procedure consists of carburising the steel at a temperature of 925° C. for 6 hr. in accordance with the McQuaid-Ehn method to reveal the grain structure, and comparing this structure, as revealed at a magnification of 100 diameters, with a standard chart consisting of eight micrographs.

Freezing Temperatures of Some High-Purity Irons and of Some Steels. W. F. Roeser and H. T. Wensel. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, Apr., pp. 273–287). The authors describe an apparatus for accurately determining the freezing point of iron, carbon steel and alloy steels, and some investigations made with it. The freezing temperature of iron (99·99% pure) in an atmosphere of helium was found to be 1539° ± 1° C. The same samples of iron were found to freeze 1° C. lower in hydrogen. Tables are presented in which the freezing points of twenty-three samples of iron and steel with their chemical analyses are given, and the amounts by which the freezing points are lowered by the presence of 1% by weight of a number of elements are also stated.

Mechanism of Martensite Transformation. A. B. Greninger and A. R. Troiano. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1338: Metals Technology, 1941, vol. 8, June). The authors describe an investigation of the austenite-martensite transformation in large single crystals of an iron-nickel alloy containing 22% of nickel and 0·8% of carbon. The grain size of the specimens was about 1 cm., and these were cooled to about − 70° C. to form a few martensite crystals which were ground and polished on a surface parallel to a single martensite plate. Back-reflection Laue diagrams were obtained both before

and after tempering. By the measurement and analysis of the change in positions that a volume of austenite undergoes when it is transformed into a crystal of martensite and a stereographic projection of the pictures obtained, the authors deduce that the transformation is brought about by two shear stresses. The function of the first shear stress is to create a lattice containing a unique set of parallel atomic planes such that the atom positions and spacing of the planes are the same as those for a martensite lattice. The second shear stress on this unique plane then generates the martensite lattice.

On the Mechanism of a New Transformation, and Some Associated New Reactions in the Iron-Nickel-Aluminium System. S. Kiuti. (Report of the Aeronautical Research Institute, Tokyo Imperial University, 1940, vol. 15, Dec., No. 203, pp. 601–720). The author has suggested in earlier work that the large coercive force of alloys of iron with about 20–30% of nickel and 10·5–12·5% of aluminium was not associated with the precipitation of the γ-phase from the α-phase, but with the precipitation of a new phase α'; the γ-phase, when it occurred, appeared to be metastable. In the present paper the precipitation of the new phase was studied over a range of compositions, using microscopic examination, lattice-parameter measurements, and dilatometric and magnetic methods. In the surface layers of these alloys an unstable γ-phase was observed in the early stage of annealing, which on prolonged annealing totally disappeared, the X-ray pattern showing the co-existence of the α- and α'-phases. In the interiors of the specimens, the unstable γ-phase did not appear, although by greatly prolonging the annealing (3500 hr. at 1000° C.) a splitting phenomenon of the X-ray pattern also became evident. For these reasons the new transformation $\alpha \rightarrow \alpha + \alpha'$ was introduced in this system as the main reaction instead of the $\alpha \rightarrow \alpha + \gamma$ change noted by previous investigators. The α'-phase was identified by the author's X-ray analysis of the Fe–Ni–Al system as the solid solution of the intermetallic compound NiAl. A new ternary diagram of the system is presented.

X-Ray Study of a New α'-Phase in the Magnetic Iron-Nickel-Aluminium Ternary Alloy System. S. Kiuti. (Japan Nickel-Review, 1941, vol. 9, Apr., pp. 78–104). The author refers to Köster's conclusion that the high coercivity of the iron-nickel-aluminium alloys is due to precipitation of γ-phase (face-centered cubic lattice) from the matrix of the α-phase (body-centered cubic lattice), with which he disagrees because of the results of his own X-ray investigation of the system, a full account of which is given in the present paper. The author found a new α'-phase and came to the conclusion that the high coercivity of this alloy series is attributable to the precipitation of α'-phase (body-centered cubic lattice with the superstructure of the CsCl type) from the matrix of the α-phase, and that this necessitates a revision of the iron

corner of Köster's constitutional diagram of this ternary system. (*See* preceding abstract).

CORROSION OF IRON AND STEEL

The Significance of Laboratory Tests for the Investigation of the Corrosion of Steel. W. J. Müller. (Stahl und Eisen, 1941, vol. 61, May 29, pp. 535–536). The author discusses the interpretation of laboratory tests when formulating theories on the corrosion of steel. He points out that he has shown experimentally and proved theoretically that when corrosion takes place with the formation of hydrogen, the main cause is the hydrogen overvoltage at local cathodes, and that in corrosion due to oxidising agents the governing factor is the amount of the oxidising agent which reaches the corrosion-sensitive metal by diffusion through the surface material. From this it follows that the rate at which acids attack steel depends mainly on the impurities in the steel, whereas the rate of corrosion by oxidising agents (*e.g.*, the rate of rust formation in the atmosphere) does not depend on the impurities but on the rate of diffusion of the agent through the surface material.

Embrittlement and Intercrystalline Cracking of Boiler Steels. J. W. Donaldson. (Metal Treatment, 1941, vol. 7, Summer Issue, pp. 45–49). The author reviews the results of German, American and British investigations on the causes and methods of combating the intercrystalline cracking or caustic embrittlement of boiler steels.

Corrosion in Steel Tank Rectifiers. (Electrical Times, 1941, vol. 99, June 12, pp. 373–374). A method of combating the corrosion of metal-clad water-cooled mercury arc rectifiers is described. The most effective inhibitor has been found to be sodium dichromate, and for most waters available for cooling, a 0·5% solution has proved satisfactory; this requires 4·2 lb. of crystals to every 100 gal. of cooling water; for waters of exceptional purity a lower percentage can be used. The life of the chromate solution depends on the amount of make-up water added to the closed circulating system.

ANALYSIS

Sampling of Materials. G. Murphy. (A.S.T.M. Bulletin, 1941, May, pp. 25–28). The author discusses factors influencing the number of samples which should be selected for test and how they

should be selected from a consignment of steel in order to be representative of the whole.

An Improved Combustion Carbon Train. E. T. Saxer and R. Minto. (Blast Furnace and Steel Plant, 1941, vol. 29, May, pp. 519–521). In making carbon determinations by the combustion process the authors have experienced difficulty when using oxygen from a high-pressure cylinder and the standard type of regulator which is designed for welding. In the present paper they describe the carbon combustion train which they developed to overcome this. In this case the oxygen comes from a central distributing plant to the laboratory at a pressure of 125 lb. per sq. in., and a regulator with an 8-in.-dia. diaphragm is used which enables very sensitive control of the pressure to be maintained.

Apparatus for the Determination of Hydrogen in Steel and Iron by the Vacuum Heating Method (I). Micro-Analysis Apparatus. T. Somiya. (Tetsu to Hagane, 1941, vol. 27, Mar. 25, pp. 184–190). (In Japanese).

Determinations of Hydrogen in Ferrous Materials by Vacuum Extraction at 800° C. and by Vacuum Fusion. V. C. F. Holm and J. G. Thompson. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, Mar., pp. 245–258). The authors report on a study of the applicability of the vacuum-fusion and warm-extraction methods to the determination of hydrogen in ferrous materials, and of the accuracy of these methods. The warm-extraction method has the advantages of rapid operation and relative freedom of the evolved hydrogen from association with other gases. A high hydrogen content produced by heating the metal in hydrogen at a high temperature, or by electrolysis, is unstable at room temperature, but the hydrogen content in commercial steels, after hot-working and storage, is low and stable, and does not cause segregation. Steels with a high chromium content dissolve more hydrogen and retain it more tenaciously than do plain carbon or low-alloy steels. It was evident from the results obtained that the over-all precision of the vacuum-fusion procedure was less than that of the warm-extraction procedure, although the vacuum-fusion blank is the lower and more precise.

Colorimetric Determination of Phosphorus in Steel and Cast Iron. J. L. Hague and H. A. Bright. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, May, pp. 405–413). The authors describe an application of the phospho-molybdenum blue reaction to the determination of phosphorus in steels and irons. In the procedure described, a reagent containing hydrazine sulphate and ammonium molybdate is used to form the blue compound, and the transmittancy of the coloured solution is measured with a photo-electric colorimeter. A single determination can be made in about 20 min., and with steels containing phosphorus in the range 0·01–0·11% the results are accurate within $\pm$ 0·003%.

The Application of Spectrographic Methods to the Analysis of Segregates. F. G. Barker, J. Convey and J. N. Oldfield. (Iron and Steel Institute, 1941, this Journal, Section I.). Reference is made to preliminary experiments which showed that routine methods of spectrographic analysis were not applicable to the quantitative analysis of segregates without some modification. Further experiments made with standard graphite electrodes, silver electrodes of various shapes, and various spark gaps to reduce the area affected by sparking are described, also other variations in procedure which were found necessary to increase the line density of the spectrum to permit of estimations being made from a single exposure. Conditions are stated under which the elements silicon, manganese, nickel, chromium, molybdenum and vanadium can be estimated from one exposure of 15 sec. The diameter and depth of the crater formed under these conditions are approximately 0·012 in. and 0·0007 in., respectively, and the weight of metal actually involved in the test is approximately 0·000005 g. It is shown that tests on small bars of nickel-chromium-molybdenum steel give reproducibility of a satisfactory order, and that tests on specimens from large forgings of nickel-chromium-molybdenum and nickel-vanadium steel containing segregates give higher average values for all elements on the segregates than on the normal metal, the greatest percentage increase occurring for manganese, molybdenum and vanadium.

Experiments in hand to obtain continuous spectrograms showing the variation in composition, if any, which exists within the segregates are also described.

New Instrument Transforms Hours into Minutes in Making Metal Analyses. (Steel, 1941, vol. 108, June 2, pp. 69–70). A brief illustrated description of a recording microphotometer for examining spectrograms is presented. The equipment consists of two units, the scanning instrument and the recording instrument. The spectrogram is placed in the scanning unit and a beam of light is made to pass across it and fall on a photo-electric cell behind it ; the variations of the current passing through the cell correspond with the density of the spectrum. The recording instrument produces a continuous line on a chart which represents the current fluctuations in the cell circuit and, by comparing this with records of standard spectrograms, a quick and accurate method of interpreting the spectrogram in the scanning instrument is provided.

A Simple Gas Testing Appliance. J. G. Lewis. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, June, pp. 52–54). The author describes a simple apparatus for determining variations in the hydrogen content of an annealing-furnace atmosphere. The apparatus consists of a porous pot covered by an inverted beaker resting on a base. There are tube connections through the base ; two of these are for the annealing atmosphere to enter and leave the space surrounding the porous pot, and the third, through the

centre of the base, connects a manometer to the inside of the pot. The theory of the instrument is based on Graham's law of diffusion, namely, that the rate of diffusion of a gas through a porous pot is proportional to the partial pressure difference of that gas across the pot, and is inversely proportional to the square root of the gas density. The pressure fluctuations corresponding to the limits of useful gas composition are soon found by trial and error, or by calibration against a gas analysis apparatus.

A Manometric Gas Analysis Apparatus. M. Shepherd and E. O. Sperling. (Journal of Research of the National Bureau of Standards, 1941, vol 26, Apr., pp. 341–346). The authors describe an apparatus and a procedure for the analysis of gas mixtures under the following conditions : (1) When the volume of the sample is small (about 5–0·5 ml.) and a reasonably accurate analysis is desired ; (2) when the volume of the sample is of the order of 0·2–0·1 ml. and an approximate microanalysis is desired ; and (3) when the gases to be analysed are dissolved in some liquid from which they must be liberated prior to analysis.

An Apparatus for the Absorption or Gravimetric Determination of Constituents of a Gas Mixture. M. Shepherd and H. W. Bailey. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, Apr., pp. 347–349). The authors describe an apparatus which eliminates many of the undesirable features of certain types of absorption trains which are used for gas analysis where one or more constituents of a gas mixture are removed by reaction with solid or liquid reagents either for purification or for the gravimetric determination of the absorbed constituents.

Modifications of Apparatus for Volumetric Gas Analysis. M. Shepherd. (Journal of Research of the National Bureau of Standards, 1941, vol. 26, Apr., pp. 351–356). The author describes some modifications to an apparatus previously described (*see* Journ. I. and S.I., 1931, No. I., p. 775) for the volumetric analysis of gas by combustion and absorption methods.

Determination of Total Moisture in Coke. A. C. Bose and N. N. Das Gupta. (Tisco Review, 1941, vol. 9, Feb., pp. 84–87 ; Mar., pp. 178, 183). The authors describe an investigation of the influence of size, weight of sample and temperature and duration of heating on the results obtained when determining the total moisture in coke. It was found that results obtained from tests on samples crushed from large pieces were generally higher than those obtained from fine pieces, especially pea size. Samples prepared from the exterior of the coke pieces contained more moisture than those from the interior. Samples of 1 kg. of coke breeze and of coke crushed to pea size required heating on an electric hot plate for 4 hr. at a temperature of 115–125° C. to drive off all the moisture. For larger pieces 6 hr. at the above temperature or 4 hr. at 200° C. was required. In general it was found advisable to crush without delay the entire sample received to pieces between $\frac{1}{2}$ in. and $\frac{3}{4}$ in. in

size and to mix and quarter the heap. The heating should be done in galvanised-iron pans about $\frac{1}{32}$ in. thick at a temperature of at least 115° C., but never higher than 200° C.

BOOK NOTICE

SOCIETY OF CHEMICAL INDUSTRY. *Reports of the Progress of Applied Chemistry.* Vol. XXV–1940. 8vo, pp. 603. London : Society of Chemical Industry. (Price 7s. 6d. to Members of the Society, 16s. to others.)

This volume consists of surveys by leading authorities on the progress in 1940 of applied chemistry in its numerous branches. The reports contained in the present volume, many of which are of interest to those engaged in the manufacture of iron and steel, are as follows : General Plant and Machinery, by M. B. Donald; Fuel, by J. Hiles and R. A. Mott; Gas, Destructive Distillation, Tar, and Tar Products, by H. Hollings and W. A. Voss; Mineral Oils, by W. W. Goulston; Intermediates and Colouring Matters, by R. Fraser Thomson; Fibres, Textiles and Cellulose : The Protein Fibres, by C. S. Whewell; Cellulose Textile Chemistry, by R. J. B. Marsden; Pulp and Paper, by J. Grant; Acids, Alkalis, Salts, etc., by P. Parrish and F. C. Snelling; Glass, by A. Cousen; Ceramics, Refractories, and Cement, by H. W. Webb; Iron and Steel, by S. J. Kennett; Non-Ferrous Metals, by A. R. Powell; Electrochemical and Electrometallurgical Industries, by J. W. Cuthbertson; Fats, Fatty Oils, and Detergents, by T. P. Hilditch; Plastics, by Members of the Plastics Group; Resins, Drying Oils, Varnishes, and Paints, by Members of the Oil and Colour Chemists' Association; Rubber, by T. R. Dawson; Leather, by M. P. Balfe; Soils and Fertilisers, by G. V. Jacks; Sugars, by E. B. Hughes; The Fermentation Industries, by A. A. D. Comrie; Foods, by T. Moran and J. Pace; Fine Chemicals and Medicinal Substances, by N. Evers; Essential Oils, Isolates, Derivatives and Synthetics, by W. H. Simmons; Photographic Materials and Processes, by J. W. Glassett, with E. G. V. Barrett and D. J. G. Howe; Sanitation and Water Purification, by G. D. Elsdon and M. Gibson.

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ZUNKER, P. "*Versuche zur Entwicklung eines Lagermetalls auf Bleigrundlage.*" (Dresden (Techn. Hochschule), Dr.-Ing.-Diss.). 8vo, pp. 61. Illustrated. Berlin, 1939 : Wilhelm Limpert.

MINERAL RESOURCES

Manganese near Chaibasa, Singhbhum. J. A. Dunn. (Records of the Geological Survey of India, 1939, vol. 74, Part 4, pp. 467–473). Since the publication in 1909 of Fermor's work on the manganese deposits of India, further boring has exposed clearer sections of the rocks in some small deposits near Chaibasa ; these have enabled the present author to suggest an extension of Fermor's view on the origin of these deposits.

Coal in the Mirzapur District, United Provinces, and in the Adjoining Parts of the Singrauli Coalfield, Rewa State, Central India. A. L. Coulson. (Records of the Geological Survey of India, 1939, vol. 74, Part 4, pp. 433–466). The author presents a comprehensive account of the present state of knowledge regarding the coal known to exist near Kota in the Mirzapur district of the United Provinces and in the Singrauli coalfield. No good deposits of coal of first-class quality are known to exist in the area under discussion, and it would seem vain to hope for any coal better than second-class quality.

Chromite. A. L. Coulson. (Records of the Geological Survey of India, 1941, vol. 76, Jan., Bulletin No. 2). The author gives an account of the mineralogy and the metallurgical, refractory and chemical uses of chromite, describes the methods of manufacturing chromium metal, ferro-chromium, chrome bricks, chromic oxide, chromates and dichromates, and presents some statistics on the occurrence and production of chromite in India.

Russian Oil. (Overseas Engineer, 1941, vol. 14, July, pp. 189–197). In this article an endeavour is made to summarise the present oil, mineral and industrial potentialities of Russia and to give some indications of their future development, so far as this can be foreseen.

ORES—MINING AND TREATMENT

New Ore Handling Plant at Noamundi Iron Mine. F. G. Percival. (Tisco Review, 1941, vol. 9, June, pp. 445–452). The author gives a detailed and illustrated description of the recently completed iron-ore bins and the aerial ropeway at the Noamundi mine of the Tata Iron and Steel Co., Ltd., for conveying ore from

the mining lease area at Joda to Noamundi railway station for transport to the works at Jamshedpur.

Results Obtained when Magnetising-Roasting Iron Carbonate Ores. W. Luyken and H. Kirchberg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 6, pp. 81–92). The authors describe an investigation of the possibility of preparing a concentrate suitable for reduction in the blast-furnace from two Siegerland and one Italian iron-carbonate ore fines by magnetising-roasting. The tests were carried out using the rotary kilns described in a previous paper by Luyken and Kremer (see Journ. I. and S.I., 1939, No. I., p. 200 A), which was slightly modified for the purpose. The ore passed through the upper kiln in the opposite direction to the neutral heating gas ; the moisture was driven off first and then the carbon dioxide ; the product next passed into the lower cooling kiln, where the evolved gases, rich in carbon dioxide, passed over it. In this zone the formation of ferrosoferric oxide took place at a temperature above 250° C., and the product then cooled down as it traversed the lower portion of the kiln. Both kilns were so constructed that no outside air could enter them. The results showed that a roasted ore of uniform magnetic properties suitable for high concentration by magnetic separation could be produced from all three of the ores tested. Full details of the results are given in tables. The removal of the copper from the Siegerland ores was also studied, and it was demonstrated that nearly all the copper could be removed with the gangue by magnetising-roasting, provided that steps were taken to remove the oxygen from the gases passing through the cooling kiln.

The Production of Self-Fluxing Agglomerate from Magnitogorsk Ore and the Production from it of Pig Iron. N. Yakubtsiner and I. Gorelik. (Stal, 1940, No. 5–6, pp. 1–13). (In Russian). A very detailed account is given of an investigation of the production of a self-fluxing agglomerate from Magnitogorsk ore. This was carried out in three stages, the first comprising the determination of the optimum proportions of the constituents of the agglomerate as produced on a large laboratory scale ; in the second, the production of self-fluxing agglomerates on an industrial scale by the Dwight-Lloyd process was examined ; the third stage was a study of the working of No. 3 blast-furnace (of 1180 cu. m.) at the Magnitogorsk Works when charged with the self-fluxing agglomerate. The preliminary experiments showed that for optimum results the charge should contain 5·8–6·0% of carbon and 8–10% of moisture. Sufficient limestone, which may contain MgO, should be added so that $(CaO + MgO) : SiO_2 = 1$. The presence of MgO is favourable and part of the limestone may be replaced by dolomite. The grain size of the limestone should not exceed 5 mm. The average porosity of the agglomerate was 43%. Agglomerates produced on an industrial scale (no difficulties were encountered) had the average

composition : Total iron 52·77% FeO 23·39%, SiO$_2$ 11·67%, CaO 7·62% and MgO 1·80%. Mineralogically the agglomerates contained gehlenite (3CaO.Al$_2$O$_3$.2SiO$_2$), calcium fayalite (Ca.Fe.SiO$_4$), hedenbergite (Ca.FeSi$_2$.O$_6$) and pseudo-wollastonite (β.Ca.SiO$_3$). In the presence of magnesium, åkermanite (4CaO.MgO.3SiO$_2$) was also formed. The working of the blast-furnace when the self-fluxing agglomerate was added to the burden was primarily characterised by exceptional steadiness, lower coke consumption and higher output. The use of self-fluxing agglomerate is particularly advantageous in connection with lean ores requiring more flux. It also permits the utilisation of limestone and dolomite quarry fines and friable limestones.

REFRACTORY MATERIALS

(Continued from pp. 107 A–108 A)

The Application of Equilibrium Diagrams to the Study of Refractory Materials. N. E. Dobbins. (Refractories Journal, 1941, vol. 17, June, pp. 203–215). The author explains the application of equilibrium diagrams to the study of the reactions which take place between refractory bricks used for blast-furnace and steel-furnace linings and the slags formed in these furnaces. It is seen from the examples given that a study of the phase equilibria of the more abundant components present usually enables the general behaviour of refractory materials under specified conditions to be predicted, and where discrepancies do occur between the observed and the expected behaviour, these are in most cases due to differences in the physical properties of the reactants and products.

The Viscosity of Slags and Glasses. Part III. The Relation between the Viscosity of Slags and their Attack on Refractory Materials. J. R. Rait and A. T. Green. (Transactions of the British Ceramic Society, 1941, vol. 40, June, pp. 231–266). This paper concludes the series on the viscosity of slags and glasses (*see* p. 111 A). The literature on the relation between the viscosity of glasses and slags and their attack on refractories is reviewed, and it is shown that the slagging of refractories is a complex reaction between a complex liquid and a heterogeneous solid producing a material which melts at a lower temperature than the temperature of operation. Such reactions are affected by the physical properties of the attacking liquid, the refractory and the product of reaction. From the chemical aspect, the solubility of the refractory in the attacking liquid is of chief importance ; theoretically, this expresses the maximum possible slagging. Interfacial tension and wetting power, viscosity, density, and size of the molecules of the slag and

product of reaction, and the physical properties of the refractory, which control the penetration of the slag, determine the extent to which this slagging occurs.

The Behaviour of Fireclay Aggregates with Additions of Graphite. F. Harders. (Stahl und Eisen, 1940, vol. 60, May 30, pp. 475–478; June 6, pp. 502–507). The author reports on an investigation of the properties of stoppers and spouts made from refractory aggregates with additions of different percentages and types of graphite. Data are presented relating to the analysis, specific gravity, porosity, Seger cone number, resistance to slag attack, to thermal shocks and to the action of ferrous and manganous oxides, refractoriness under load, and the dimensional changes with temperature of seven commercially available stoppers containing graphite, one without graphite, and eight specially prepared blocks of different composition, some with and some without graphite. These tests proved that the softening point, refractoriness under load, resistance to slag attack and resistance to thermal shock of stoppers made with graphite additions to the aggregate are, generally speaking, considerably better than those made of fireclay and alumina without graphite. If the Seger cone number of one stopper is higher than that of another, it does not necessarily follow that the refractoriness under load will also be better. The porosity of stoppers containing graphite was practically the same as that of comparable fireclay stoppers. The resistance to slag attack varied greatly, and with some of the stoppers containing graphite it was scarcely any better than that of a fireclay brick. A fireclay stopper was attacked more strongly by ferrous oxide than by manganous oxide, but when the stopper contained graphite the reverse applied. The dimensional changes of stoppers with and without graphite on heating were approximately the same. The properties of the ash from the graphite addition had an important bearing on the effect of the graphite addition. The use of carbon recovered from coal-washery heaps as an addition to fireclay refractories was not found to be practicable, probably because of the quantity of low-melting-point ash which it contained.

Investigation of the Heating-Up Process of a Furnace Lining and a New Method of Calculating Linings. I. Rafalovich. (Stal, 1940, No. 5–6, pp. 36–43). (In Russian). Experiments were undertaken to study the heating up of an experimental furnace wall under conditions of normal, excess and reduced air pressure within the furnace. The results plotted graphically are compared with those derived by several analytical methods, some of which under certain conditions gave satisfactory results. A new method of calculating the heat losses when heating up the furnace walls is given. The method is based on an analysis of experimental results and is applicable also for excess or reduced pressure conditions within the furnace, provided gas leakage through the walls is prevented. The application of the method to the choice of an

optimum wall design for a given furnace heating-up curve is illustrated.

Practical Application of 'Monolithic Linings in Cupolas. F. Oldershaw. (Refractories Journal, 1941, vol. 17, Aug., pp. 275–279). The author describes the procedure adopted to construct a 13-in.-thick rammed monolithic lining inside a cupola about 6 ft. 6 in. in dia. inside the shell. A proprietary monolithic lining material was used. In another cupola with a monolithic lining a mechanical weakness occurred at a position between 5 in. and 7 in. from the face, due partly to the material remaining unvitrified at this depth. This was repaired by using only a small amount of patching after each blow until the diameter of the lining at that part had become larger by 8–10 in. This procedure allowed the unconverted part, or backing where rupture had occurred, to become strong again by vitrification, and it also formed a strong foundation for the new lining which was rammed on the old one. The effect was that of vitrifying the lining from back to front and thus forming a lining with the strength of firebrick but without the undesirable joints.

Coke Oven Refractories. W. C. Rueckel. (American Gas Association : Refractories Journal, 1941, vol. 17, July, pp. 239–251). The author has studied the properties of silica bricks and their application for lining coke-ovens. He compares the expansion, thermal conductivity and the refractoriness under load of fireclay and silica bricks and examines the causes of failure of oven walls of batteries which were being dismantled after long service. In conclusion he makes recommendations on the patching of eroded areas with suitable cements.

FUEL

Tromp Washers at a Derbyshire Colliery. (Iron and Coal Trades Review, 1941, vol. 143, Aug. 1, pp. 91–93). A description is given of a Tromp coal-washing plant which is operating successfully at a Derbyshire colliery. The Tromp process is unique in that it is the only one in which an unstable suspension is purposely employed. The solid medium is magnetic, but the process lends itself to the use of other media ; in fact, sintered ore is now being used at the plant described owing to the impossibility of obtaining sufficient magnetite.

Addition of Oils to Washed Coals. G. Deshalit and M. Rott. (Koks i Khimiya, 1940, No. 1, pp. 12–15). (In Russian). Laboratory tests have shown that an addition of at least 1–1·5% (preferably 3–4% by weight of dry coal), of straw oil, or of heavy coal tar

oil will prevent the freezing together of washed coals with a moisture content of up to 16% at temperatures down to − 20° C. In this way difficulties in connection with the transport of washed coal in railway trucks in cold weather can be overcome.

The Oiling of Washed Coals. I. I. Azbel and N. Almazov. (Koks i Khimiya, 1940, No. 1, p. 15). (In Russian). A short note with a diagrammatic illustration refers to the first plant built in the U.S.S.R. for the oiling of washed coal to prevent it from freezing together. The plant started in January 1940 and has been operating satisfactorily. Railway sleeper impregnating oil is used, and the average consumption is 0·75% by weight of the coal treated.

Dehydration of Coal by a Preliminary Coating of its Surface with Oil. P. D. Lysenko. (Koks i Khimiya, 1939, No. 12, pp. 18–19). (In Russian). Some preliminary results show that the removal of water from coal after washing can be rendered more efficient by a preliminary coating of the coal with oil. Anthracene oil from which the anthracene has been removed has been found to be most effective. The amount used is about 0·8–1% of the coal being treated. An additional advantage of the treatment is that small particles of coal stick to the larger particles and the amount of sludge produced in the washing process is reduced. Water can be removed on a vibrating screen or by means of a centrifuge.

Coking in South Africa. C. D. Terry. (Coke and Smokeless-Fuel Age, 1941, vol. 3, May, pp. 104–107 ; June, pp. 130–136). The author presents an illustrated account of the development of the coke and by-product industry in South Africa. A battery of 30 stamp-charged horizontal ovens was first erected at Waschbank, Natal, in 1922. In 1926 an additional 20 ovens were erected, and in 1939 the original 30 ovens were rebuilt from just above the waste-heat flue level. At the present time these 50 ovens are producing 6300–6400 tons (of 2000 lb.) per month. In 1934 a battery of 57 Becker combination regenerative ovens with a modern by-product plant was put in commission at Iscor, Pretoria ; a blend of 75% Transvaal coal and 25% Natal coal is carbonised in these ovens. An interesting feature of this plant is the use of dry cooling chambers into which the coke is discharged from the ovens ; from this source of waste heat approximately 1000 lb. of steam are generated per ton of coke cooled. Another battery of 45 top-charged Becker ovens is now under construction at Iscor. In the second part of the article the author explains the importance of tar as a factor in the development of new national highways in the Union of South Africa, and gives specifications for tars, oils, solvents and other by-products.

Swelling Pressures in Coke Ovens. J. Roberts. (Coke and Smokeless-Fuel Age, 1941, vol. 3, June, pp. 128–129). The author advances some theories in support of the suggestion that the gas pressure which builds up within the plastic layer of a charge in a coke-oven is the principal cause of the pressure exerted by the

charge on the oven walls. He also discusses the difference of opinion between the United States Bureau of Mines and Mott and Spooner on the question of swelling pressure (*see* p. 37 A).

New Method for Determining the Coking Properties of Coals. S. A. Anurov and E. V. Zatsepina. (Koks i Khimiya, 1940, No. 6, pp. 3–6). (In Russian). The authors describe methods of testing the coking properties of coal. The samples are passed through a 1-mm. mesh sieve and carbonised in cylindrical iron containers open at both ends, a number of which are clamped between two iron discs. Carbonisation is carried out at 550° C. for 15 min. The weight of liquid which runs out during carbonisation is determined. This gives a measure of the swelling of the coal, and the weight of the lumps of coke formed minus the fine fraction passing through a 2-mm. sieve (this gives a measure of the coking property of the coal), and finally the strength of the lumps is determined. The latter is determined by tumbling the lumps with porcelain balls in a tubular container rotated with its axis in a vertical plane, and ascertaining the percentage of fine fraction (passing through a 2-mm. sieve) formed. The tumbling test is repeated three times. Modified test procedures are described for swelling, slightly swelling and non-swelling coals and results for a number of Russian coals are given.

Improving the Quality of the Metal and Increasing Coking Coal Resources. S. S. Dvorin. (Koks i Khimiya, 1939, No. 12, pp. 5–11). (In Russian). Consideration of blast-furnace operating data leads the author to the conclusion that present-day tests for gauging the quality of coke as a metallurgical fuel, in particular the drum test, are antiquated. Drum-test requirements unduly restrict the grades of coal used for coking. Experimental running of a blast-furnace on coke produced from a charge to which had been added 10% of ground chalk gave satisfactory results. Grading of coke on the basis of sulphur content and the production of a low-phosphorus ($<0.01\%$) grade are also considered.

The Dust Content of Blast-Furnace Gas and Pressure Conditions in Coke Ovens. A. A. Agroskin. (Koks i Khimiya, 1940, No. 3, pp. 15–20). (In Russian). Data illustrating the effect of the dust content of blast-furnace gas obtained from observations on the coke ovens at the New Makeev works are given and compared with corresponding data for coke ovens fired with coke-oven gas. During the period of the investigation the dust content of the blast-furnace gas reached 50 mg. per cu. m. and more. Dust accumulations were found to result in pressure increases in the ovens and a pressure drop in the regenerators, as well as in reducing the efficiency of the latter. Dust in blast-furnace gas used to heat coke ovens should, therefore, be carefully controlled.

The Low-Temperature Gasification of Upper Silesian Bituminous Coal. K. Skroch. (Stahl und Eisen, 1940, vol. 60, June 27, pp. 557–563). The author gives a very comprehensive description of

the process and plant used for the low-temperature carbonisation of Upper Silesian coal, a coal the properties of which render it particularly suitable for this treatment. In this process the coal is carbonised at low temperature and the semi-coke is gasified in the usual type of producer with the production of tar and of lean gas with a calorific value of 1500 kg.-cal. per cu. m. in one continuous plant. Consumption and production data of different plants are compared from both the technical and economic points of view, and the importance of the production of lean gas as a subsiduary fuel when there is a heavy demand for coke-oven gas is stressed.

New Coefficients of the Physico-Mechanical Properties of Coke. L. M. Sapozhnikov and K. I. Syskov. (Koks i Khimiya, 1940, No. 8, pp. 3–8). (In Russian). The authors outline and discuss a scheme for the determination of three physico-mechanical characteristics of blast-furnace coke and consider their relation to the behaviour of coke in the blast-furnace. The drum test is used for the determination of the strength of the coke, the results being expressed in terms of work done plotted against the total surface area (determined by close sieving) developed by the coke in the drum. The curve obtained has an initial curved portion which characterises the initial breaking up of the lumps of coke due to the cracks originally present, and a subsequent straight-line portion over which the surface developed is proportional to the work done. The first portion of the curve can be used to characterise the lump strength of the coke (with cracks), and the second straight-line portion the strength of the coke material itself. The authors then determine the progressive change in screen analysis of the coke and plot this against the work done on the coke in the drum. This is an important characteristic, as the progressive change in screen analysis provides an indication of the state of the coke at different levels in the blast-furnace. Furnace operating data (blast and burden permeability figures) obtained with several different cokes are given to illustrate their relation to the coefficients determined by the test methods suggested by the authors.

New Evaluation of Coke for Blast-Furnaces. P. A. Shchukin. (Koks i Khimiya, 1940, No. 6, pp. 6–9). (In Russian). The main requirements which blast-furnace coke should satisfy are : (1) Uniformity in lump size before charging into the furnace ; (2) mechanical strength of the lumps ; and (3) absence of fines. While there is no apparatus which would enable the determination of a representative characteristic, the author suggests that useful information can be obtained by a suitable interpretation of the results of the shatter and drum tests. The former are evaluated using the formula $K_1 = A/(B + C)$ where K_1 is the coefficient of uniformity of the coke and A, B and C are respectively the percentages of the 40–80 mm., 25–40 mm. and <8 mm. fractions after the shatter test. The results of the drum test are evaluated using the formula : $K_2 = Q/(410 - Q)$ where K_2 is the coefficient of mechanical strength

of the coke, Q is the residue of coke in the drum in kg. and 410-Q is the amount of small pieces below 25 mm. which have dropped through. Both coefficients should be as high as possible, and a useful representative coefficient K is given by the product of K_1 and K_2.

The Quality of Foundry Coke. L. Ya. Kolyandr. (Koks i Khimiya, 1940, No. 2, pp. 12–16). (In Russian). Published information on the effect of the quality of foundry coke is reviewed and experimental results obtained with a 2·81-cu. m. cupola (with a designed output 4 tons per hr.) are discussed. Attempts were made to relate various properties of the coke to the output, to the mean temperature of the metal and to the coke consumption per ton of metal in the cupola. It was found that the drum test figure was not conclusive. While a low figure is undesirable, it does not follow that the higher the figure the more suitable is the coke as fuel for the cupola. Determination of the reaction capacity of a finely ground sample does not give characteristic results. More informative results could probably be obtained by determining the burning capacity of large pieces of coke in amounts of 25–50 kg. In connection with such determinations, as well as with the behaviour of the coke as a fuel in the cupola, the screen analysis of the coke is of the greatest importance. The 0–40 mm. fraction should be a minimum.

Purification of Air and Gases. (Iron and Steel, 1941, vol. 14, July, pp. 386–388). The changes in the properties of a substance when it is divided into fine particles and dispersed into air or gas are discussed and the principles of wet and dry filters for cleaning gases are explained. A detailed description is then given of the Traughber froth flotation filter, in which the intimate contact between large surfaces of gas and washing liquid is obtained by a simple yet effective method of atomising the liquid. A smooth-faced cylinder, rotating at a suitable speed in contact with the surface of a pool of liquid, picks up a film of this liquid and sprays it with considerable force in the form of a fine mist, sending it splashing, with the gas to be cleaned, against the sides of the filter. The character of the mist, the density of the droplets, their size and the volume of mist, can be regulated by choosing the right diameter of cylinder, and by regulating its speed of rotation and the depth of immersion in the pool. The spray rotors, having practically no resistance to overcome, required very little power, between 1 and 2 h.p. being sufficient.

The Thylox Sulphur-Recovery Process. (Coke and Smokeless-Fuel Age, 1941, vol. 3, July, pp. 149–151). A description is given of the Thylox process for the removal and recovery of sulphur from town gas. The basic principle of this process is the removal of hydrogen sulphide by ammoniacal arsenic oxide and the subsequent separation of the sulphur through regeneration of the liquor with air. Some operating results are quoted from Thylox plants in com-

mission in America, Germany and Japan; some difficulties en-
countered at one of the Japanese plants are discussed and the
suitability of the process for British conditions is considered.

Gas-Fired Open-Hearth Furnaces. G. M. Parker. (American
Gas Association : Steel, 1941, vol. 108, June 30, pp. 66–68). The
author discusses the use of natural gas in conjunction with oil for
heating open-hearth furnaces, and gives brief particulars of a firing
arrangement in which the oil burner is above the gas burner.
Experiments are now being conducted to develop a burner in which
natural gas at relatively low pressure (25–50 lb. per sq. in.) will be
used to atomise the oil, thus avoiding the expense of supplying
steam for this purpose.

**Increasing the Life and Production of Coke-Oven-Gas-Fired
Open-Hearth Furnaces by the Addition of Pulverised Brown Coal.**
A. Mund. (Stahl und Eisen, 1940, vol. 60, June 20, pp. 537–542 ;
June 27, pp. 563–567). The author describes an investigation of
the effect of adding pulverised brown coal to carburet the coke-oven
gas used to heat open-hearth furnaces on the life and production
of the furnaces. The total production of an open-hearth furnace
in one campaign is dependent on the hourly melting capacity of the
furnace and its life, *i.e.*, the length of the campaign. When a
furnace is fired with coke-oven gas carburetted with pulverised
brown coal, the amount of brown coal added determines the amount
of heat consumed and the production per hour. With the 55-ton
furnaces used, the optimum addition of brown coal was found to
be about 50 kg. per ton of steel produced. The higher temperatures
necessary for the production of chromium and chromium-nickel
steels necessitated using chrome-magnesite bricks for the roof.
The exact control of the supply of heat and the changes in tempera-
ture of the exit gases during the campaign of a chrome-magnesite-
lined furnace are critically discussed, and it is demonstrated that
insulating the furnace and using these bricks contributed to a
substantial saving of fuel and an increase in the production.

PRODUCTION OF IRON

Metal Heaters and the Problem of Heat Supply of Metal Combines.
V. Pashkov. (Stal, 1940, No. 4, pp. 42–50). (In Russian). The
substitution of metal recuperators for blast-furnace stoves is dis-
cussed and the designs of installations in Europe in which metal
heater systems are used to heat the blast are considered. These
installations generally incorporate a Velox boiler. It is pointed
out that up to 70% of the thermal energy of the steam supplied to
the blowers is wasted in the condensers. There also appear to be

difficulties in connection with the piping of the hot air (700° C.) over long distances. A scheme put forward by the author consists of a mercury boiler fired with blast-furnace gas, the mercury vapour being used to drive the blast turbine. The spent mercury vapour from the turbine passes into a condenser, which at the same time serves to preheat the compressed air. This is subsequently heated to the required temperature by the waste gases from the mercury boiler. The economics of the scheme are considered. On the basis of experience with mercury installations in the U.S.S.R., the building of blast-heating installations along the lines suggested at a works in the Urals was authorised by the Commissariat for Heavy Industry in September, 1939. In open-hearth furnaces, it is suggested a mercury boiler could be placed in the flue, the vapour being used to drive mercury turbo-generators, which would supply the electrical energy of the Metal Combine, whilst the waste gases could be used in metal recuperators to preheat the furnace air and gas supply. Finally the rolling-mill reheating furnaces could be fired with blast-furnace gas which would be preheated in the condensers of the generator plant. The scheme would result in a fuel saving of 280 kg. per ton of pig iron.

Automatic Reversal of Dampers of Blast-Furnace Stoves. N. Leonidov. (Stal, 1940, No. 3, pp. 5–10). (In Russian). The author considers the principles of different types of systems for the automatic operation of the various dampers of blast-furnace stoves. The characteristics of pneumatic, hydraulic and electrical systems are discussed with reference to Russian designs of equipment. The necessity of using some electrical accessory items in the pneumatic and hydraulic systems, their risk of freezing and the impossibility of effecting ignition of the fuel gas by the pneumatic system render the electrical system of operation preferable. Systems which have been designed are regarded as experimental and improvements are suggested.

Automatic Control of the Stoves of a Blast-Furnace. V. Il'inskiy. (Stal, 1940, No. 3, pp. 11–15). (In Russian). The design of the electrically driven valve- and damper-operating equipment for a 1300-cu. m. blast-furnace is described with reference to the working of the various parts, the type and power of the driving motors and to circuit diagrams. The control in question operates eleven dampers, a burner draft fan and the igniter.

The Influence of the Quality of Coke on the Working of the Blast-Furnace. A. Red'ko. (Stal, 1940, No. 4, pp. 1–8). (In Russian). The investigation, which was carried out over a period of about $3\frac{1}{2}$ months with the No. 2 blast-furnace of the Kuznetskiy Metallurgical Combine, had for its object the study of the effect of different cokes made from coal charges blended with different proportions of different grades of coal on the characteristics of the operation of the furnace. Altogether, thirteen different cokes were used during the period. Full details regarding these cokes are tabulated. Details

are also given regarding the chemical composition of the other raw materials used in the furnace during the period. The operational features of the furnace with the thirteen grades of coke are very fully characterised by the following data : Consumption of raw materials per ton of pig iron, blast consumption, yield of dust, output of iron, output of slag, output of gas, temperature of blast, blast pressure, throat temperature, composition of the blast-furnace gas and composition of the iron and slag. Average daily ore, carbon and heat balances of the furnace when working on the different grades of coke are also worked out. The behaviour of the furnace with the different grades of coke and any special observations are described and the suitability of the different cokes is discussed. The general conclusion reached is that measured properties of the coke, such as screen analysis, crackiness, porosity and even the drum-test data, cannot be related to the working of the blast-furnace if the cokes concerned, as in this case, have been prepared from charges made with different proportions of the constituent coals. It is the nature of these coals which determines the quality of the coke, which in turn can only be assessed from the output characteristics of the blast-furnace.

Heat Balances of the No. 1 Blast-Furnace of the Magnitogorsk Works. M. Ostroukhov. (Stal, 1940, No. 4, pp. 9–14). (In Russian). The heat balances of the 1180-cu. m. blast-furnace at the Magnitogorsk Works over three periods during which the furnace was operating on three different types of coke were determined. The amounts of heat supplied from all sources during the three periods amounted to 2844, 2921 and 2877 cal. per kg. of pig iron respectively ; the coke consumptions during these three periods were respectively 0·790, 0·853 and 0·826 kg. per kg. of pig iron, and the nominal daily outputs were 1435·6, 1359·0 and 1425·0 tons, whilst outputs without scrap were 1344·9, 1265·5 and 1388·8 tons respectively. Figures for the various heat losses as well as for consumption of ore and other raw materials and for compositions of slag, iron and furnace gas are given, and the results are compared with those for several other furnaces.

The Smelting of Titanium-Bearing Iron Ores in the Blast Furnace. W. Tillmann. (Stahl und Eisen, 1940, vol. 60, May 30, pp. 469–474). The author refers to differences of opinion which prevailed regarding the possibility of smelting titanium-bearing ores in the blast-furnace, and describes an investigation in which six different ore mixtures were smelted. The proportion of titanium-bearing ore in the mixtures varied between 4% and 27%. Full details of the ore analyses and mixtures, coke consumption, behaviour of the sulphur, iron production, and composition and properties of the slags produced are given. It is shown that there was no marked increase in the coke consumption and that the working of the slag presented no difficulties, and the conclusion is reached that there is no need to exclude titanium-bearing ores from blast-furnace charges

for the reason that they might cause difficulties in the blast-furnace process.

Results of the Measurement on the Teeming Temperature. S. Umino. (Tetsu to Hagane, 1941, vol. 27, Apr. 25, pp. 247–259). (In Japanese). The author discusses the results obtained when measuring the temperature of the molten iron leaving a blast-furnace.

The Present Position of Powder Metallurgy. R. Kieffer and W. Hotop. (Stahl und Eisen, 1940, vol. 60, June 13, pp. 517–527). After describing the circumstances which led to the introduction of powder metallurgy and the development of this process to its present stages, the authors discuss in detail the mechanical, electrolytic and chemical methods of producing metal powders suitable for sintering and compressing. The physico-chemical characteristics of the sintering process are dealt with and the properties of parts such as bearings, cutting tools and magnets made by powder metallurgy are described.

Short-Term Determination of Economic Results in Iron and Steel Works. K. Kleine. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, May, pp. 513–518). The present author is one of the three authors of a book entitled " Leitfaden für das Rechnungswesen in der eisenschaffenden Industrie " (Guide for Industrial Accounts in Iron and Steel Works), a review of which appeared in Journ. I. and S.I., 1939, No. II., p. 54 A. In 1938 the German Government recognised this book as the official guide to accountancy in the German iron and steel industry.

In this paper the author points out that the purpose of the book referred to was to explain the practical application of the short-time determination of economic results. He gives examples of the printed forms used in large iron and steel works in Germany and explains the development of output, stock and result accounts for each product separately, as well as on a monthly basis. The connection between the economic-result data obtained in this way and the accountant's profit and loss account is shown, and the method of evaluating economic-result data so as to be able to draw conclusions from changes revealed by the figures is explained and illustrated by an example. These determinations require the close co-operation of the technical, commercial and administrative departments of the works.

Measures of Works Economics for Increasing the Capacity of the Iron and Steel Industry. H. Rübmann. (Stahl und Eisen, 1941, vol. 61, May 8, pp. 473–478). The author describes in detail two examples of changes in process methods at an iron and steel works which led to important economies and to increased production. The first example involved changing from the use of compressed-air tools for dressing ingots and billets to " flame-conditioning " with oxy-acetylene burners. A considerable increase in the capacity of the dressing shop with a decrease of 45% in the costs was effected.

In the second example it is shown how the efficiency of a drag-line-scraper transporter for moving converter slag at a slag-grinding plant was increased.

Book-Keeping Principles and Standard Accounting Methods in the Iron-Producing Industry. F. Blom. (Stahl und Eisen, 1940, vol. 60, July 4, pp. 599–602). The author discusses some of the difficulties which arise in the practical application of the German standard accountancy procedure for iron and steel works, and how these can be overcome.

Process Regulations for Increasing the Capacity of the Iron and Steel Industry. Part II. W. Schütte. (Stahl und Eisen, 1940, vol. 60, Dec. 5, pp. 1107–1113). In the second part of this paper the author describes measures taken by a works economics department to increase the capacity of a basic Bessemer plant, to adjust the wages paid for discharging increased quantities of ore from ships, to settle wage rates on the production of rolled steel flats, and to determine the number of standard man-hours required for working a blast-furnace plant. (An abstract of the first part of this paper appeared in Journ. I. and S.I., 1941, No. I., p. 206 A).

FOUNDRY PRACTICE

Principles and Practice Involved in the Production of Steel Castings. D. Clark. (Australian Institute of Foundrymen : Foundry Trade Journal, 1941, vol. 65, Aug. 7, pp. 91–93 ; Aug. 14, pp. 112–113). The author describes Australian practice in steelmaking in the Héroult electric furnace and in the Tropenas converter for casting purposes, the preparation of moulding sand, the Randupson process, the prevention of pinholes, machining difficulties and the heat treatment and testing of steel castings.

American Synthetic Sand Practice. N. J. Dunbeck. (Institute of British Foundrymen, 38th Annual Conference : Foundry Trade Journal, 1941, vol. 65, July 17, pp. 37, 38, 41 ; July 24, pp. 61–64). The paper, which appeared originally in pre-print form, is reproduced. (*See* p. 114 A).

Synthetic Moulding Sands. E. Diepschlag. (Giesserei, 1940, vol. 27, July 12, pp. 257–262). The author studies the properties of sand grains and of sand in the mass, and explains and gives examples of methods of determining the grain size, of making screen analyses, and of calculating the total surface area of a given volume of sand, and from this its cohesive strength. An example is then given of how these calculations can be applied in order to prepare a synthetic moulding sand with specified properties from a mixture of quartz sand and clay.

Principles and Practice of Core-Blowing. H. H. Jones. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 65, Aug. 21, pp. 127–129). The author describes some core-blowing machines in use in some South African jobbing foundries. The types of sand used, the construction of core boxes, the position and size of the blow holes, the position of vents and the auxiliary equipment required are dealt with in turn.

Mould and Core Washes. W. Y. Buchanan. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 65, July 31, pp. 73–75). The author's paper presented at the 38th Annual Conference of the Institute of British Foundrymen is reproduced. (*See* p. 115 A).

Mould Construction. E. Longden. (Iron and Steel, 1941, vol. 14, June, pp. 356–358 ; July, pp. 383–385). The author describes the preparation of moulds using green sand, dry sand, loam and skin dried moulds with special reference to the location of gates, and discusses the design of moulding boxes, chaplets and other moulding accessories.

Two Methods of Moulding a Drum Casting. W. Gudgeon. (Foundry Trade Journal, 1941, vol. 65, Aug. 7, p. 95). The author describes the moulding technique employed at an iron foundry for making a winding-drum casting 5 ft. 2 in. in dia. at the top, 4 ft. 2 in. in dia. at the bottom and 17 in. high.

Arsenal Makes Ordnance Castings. P. Dwyer. (Foundry, 1941, vol. 69, June, pp. 54–55, 132–134). The author describes the equipment and foundry technique employed in making all sizes of ordnance castings at the Rock Island Arsenal, Illinois.

How to Produce High-Silicon Acid-Resisting Castings. F. Marsden. (Iron Age, 1941, vol. 148, July 10, pp. 54, 120). An article on the special precautions which have to be taken in the production of high-silicon (14·5–16%) acid-resisting castings is reproduced. This paper appeared originally in Foundry Trade Journal, 1941, vol. 64, Jan. 23, pp. 51, 64. (*See* Journ. I. and S.I., 1941, No. I., p. 122 A).

Development of the Centrifugal Casting Process for the Production of Cast Iron and Steel Tubes. N. Ermolaev. (Stal, 1940, No. 5–6, pp. 70–74). (In Russian). The progress of centrifugal casting abroad is reviewed and developments in this field in the U.S.S.R. are dealt with.

PRODUCTION OF STEEL

Some Remarks About the Theory and Design of Open-Hearth Furnaces. M. Glinkov. (Stal, 1940, No. 3, pp. 16–20). (In Russian). The first section is devoted to a consideration of the

heat transfer and heat balance in the working space of an open-hearth furnace. Some expressions for heat transfer are derived and the effect of the presence of either the solid or molten charge on heat transfer is considered. Temperature conditions and heat distribution in the working space are considered in the next section. Limits are imposed by refractoriness of the lining, but the temperature of the flame should be as high as possible. To obtain a constant surface temperature of the lining, the temperature of the gases should be higher the lower the temperature of the metal and the lower the ratio of the surface area of the lining to the surface area of the charge. For melting, the higher the temperature of the flame for a constant temperature of the lining the better. The intensity of heat exchange in the working space will be the greater the smaller the temperature gradient along the length of the flame, i.e., the higher (within limits) the temperature of the exit gases. It is stated that with insulated furnace roofs there is no need to have a lower flame temperature, but pyrometric equipment should be installed to check roof temperatures. In the concluding section the geometry of the working space is discussed.

The Manufacture of High-Quality, Low Cost Steel. P. J. McKimm. (Steel, 1941, vol. 108, June 23, pp. 62–66; July 7, pp. 68–70, 85, 92–94). The author discusses the effect of the composition of the blast-furnace charge, when making basic iron, on the subsequent open-hearth operations and on the quality of the steel produced. He considers in particular the amount of scrap and open-hearth slag which can be used in the blast-furnace, and shows that high percentages of scrap can be charged without detriment to the quality of the steel produced in the open-hearth.

What about Quality of Steel? C. H. Herty, jun., and W. G. Bischoff. (American Iron and Steel Institute: Steel, 1941, vol. 108, June 23, pp. 56–58). In the first part of this short paper C. H. Herty, jun., makes recommendations with the object of reducing the consumption of ferro-manganese in steelmaking without seriously affecting the quality of the steel. It is suggested that purchasers should be willing to accept steel containing less manganese and more carbon and/or silicon, and that the practice of deoxidising the heat before adding ferro-manganese—a practice which reduces the amount of manganese required—should receive greater attention. In the second part W. G. Bischoff shows the percentages of American steelmakers' requirements of manganese, silicon, chromium, nickel, molybdenum, vanadium and tungsten which are imported, and makes some proposals for meeting the problem of the reduced availability of nickel, chromium and manganese.

The First Results of the Working of the No. 5 Open-Hearth Furnace at the Azovstal' Works. A. Bulavkin and V. Kiselev. (Stal, 1940, No. 4, pp. 15–16). (In Russian). Data obtained from the first fifty heats of the No. 5 tilting open-hearth furnace

are briefly summarised. The furnace has a hearth area of 60 sq. m. and is designed to take charges of 400–500 tons. It is fired with a mixture of coke-oven and blast-furnace gases (calorific value 2200 cal. per cu. m.). The charges in the heats investigated were made up of molten pig iron 50–60% (of the weight of the metallic charge, remainder being scrap), iron ore 8–16%, manganese ore 2–3%, limestone 6–8%. The pig iron was added 1–1½ hr. after the solid portions of the charge had been added. Observations made suggest the desirability of increasing the heat supply to the furnace in order to accelerate the heating up during charging and the rate of carbon elimination. The limestone should be replaced by lime, and 1–1·5% of bauxite should be added to improve the fluidity of the slag.

The Influence of the Basic Factors of Open-Hearth Practice on the Quality of Axle Steel Produced in Deep-Bath Furnaces. M. Medzhibazhskiy. (Stal, 1940, No. 2, pp. 11–16. (In Russian). The quality of the steel was estimated on the basis of the surface defects in blooms and the presence of non-metallic inclusions detected in machining. The effect of the various factors on both types of defect was investigated by statistical treatment of numerous works' data and by some experimental heats. An increase in the manganese and silicon contents of the steel tended to increase the non-metallic inclusions. Relatively high carbon content was favourable. It was found that surface defects and the occurrence of non-metallic inclusions varied together. Shortening the melting period, and lengthening and intensifying the boiling process were favourable. The optimum carbon content after melting was 1·1%. The charge for the 200-ton heats consisted of pig iron 70% and scrap 30%. The addition of ore for refining after melting should equal between 2% and 4% of the weight of metal charged. The period of melting (including charging) should be as short as possible. The rate of elimination of carbon and the length of the period of boiling also have an effect. The latter should be 3–4 hr. for 200-ton heats, the second finishing period of the boil being 2 hr. for optimum results. The rate of carbon elimination should be 0·005–0·006% per min. during the first refining period, and 0·0033% per min. during the second finishing period. The method of adding the ferro-silicon used for deoxidation has a critical influence on the number of non-metallic inclusions. It should be added after the ferro-manganese and between 15 and 20 min. before tapping. The effectiveness of the deoxidation can be gauged from the difference between the ferrous-oxide content of the slag before and after deoxidation. The optimum teeming temperature for minimum surface defects and non-metallic inclusions is 1460° C.; teeming should take 1–1½ hr. and the moulds should be filled at the rate of 1–1·5 tons per min. In conclusion, some details are given about the non-metallic inclusions observed. They were generally of the silicate type.

The Influence of Slag Practice on the Speeding Up of Carbon Elimination in Deep-Bath Open-Hearth Furnaces. S. Sapiro. (Stal, 1940, No. 3, pp. 20–23). (In Russian). By way of introduction the author discusses the principles governing the influence of the slag on the rate of carbon elimination in an open-hearth furnace. The thickness of the slag layer has no definite effect, as it is masked by other physico-chemical factors. In his experimental work the author determined the relation between the viscosity of the slag as measured by a Herty viscometer (diameter of channel 10 mm., length 290 mm.), the composition of the slag and the rate of carbon elimination. The data were obtained from twenty-two 300–320-ton heats of medium-carbon steel. In addition to presenting the results obtained, the characteristics of two heats in which the highest rate of carbon elimination, and two heats in which the lowest rates were obtained are discussed. Under the conditions of the heats concerned the thickness of the slag layer varied between 300 and 400 mm. The depth of the bath was 1·5–1·6 m. To obtain the maximum rates of elimination of carbon under these conditions—viz., 0·008–0·009% per min. during the first period and 0·0035–0·0040% per min. during the second period of the boil—it is necessary to maintain the viscosity of the slag between 80 and 100 mm. and not more than 120 mm. measured by the Herty method. With the above viscosity the CaO/SiO_2 ratio of the slag may vary between 1·8 and 2·5, depending on the degree of desulphurisation required. The degree of oxidation of the slag should be such that $\Sigma Fe = 18\text{--}17\%$ at the commencement of the ore boil and 12–11% at the end of the second period of the boil when producing medium-carbon steel.

Production of Structural Steels in Arc Furnaces. Yu. Shül'te. (Stal, 1940, No. 2, pp. 23–25). (In Russian). The melting process in the arc furnace and certain structural characteristics of steels produced in electric furnaces are dealt with. The charge is made up of iron or steel scrap, pig iron and alloy steel scrap of suitable composition. The pig iron is intended to produce a carbon content after melting of 0·5% above that required in the finished steel. Ferro-manganese is also added to the charge to give 0·5–0·8% of manganese after melting. About 1% of lime is added to protect the metal against oxidation during melting and to remove phosphorus. Dephosphorisation by means of the slag, degassing of the bath, removal of non-metallic inclusions and preparation of the bath for deoxidation are achieved during the boil. For the latter purpose the bath is held at high temperature to obtain equilibrium between the carbon and the ferrous oxide. With the white slag process, slag is first removed and aluminium and powdered ferro-silicon are added. A basic lime-fluorspar slag is made up and continuously deoxidised, mainly with ferro-silicon. During tapping 0·7 kg. of aluminium per ton of steel is added. In the combination method, after the removal of the oxidising slag, a basic lime-

fluorspar slag is made and deoxidation is effected mainly with coke, with some ferro-silicon, with a final addition of 1 kg. of aluminium per ton to control the grain size of the austenite. The combination method is regarded as more efficient from the point of view of removing non-metallic inclusions. The fracture structure of cast steels is discussed with reference to the relation between the grain size thus revealed and the macro-defects. Fine grain is associated with freedom from macro-defects and *vice-versa*. Other conditions being equal, the fracture structure appears to depend on the final deoxidation practice.

A Consideration on the Velocity of Decarburisation during Oxidation or Boiling Period in Basic Electric Furnace. H. Sawamura and H. Zah-ming. (Suiyokwai-Shi, 1941, vol. 10, May 25, pp. 437–446). (In Japanese). The authors consider formulæ for calculating the rate of carbon removal in the bath of a basic electric furnace.

Ingot Surface and Mould Washes. P. Yakovlev. (Stal, 1940, No. 4, pp. 17–18). (In Russian). The experience gained at the Elektrostal Works with a number of ingot-mould washes is briefly summarised. Varnish with 25% of aluminium powder tended to contain moisture, but was found suitable for certain steels. Petroleum pitch with 25% of aluminium powder was satisfactory when applied uniformly as a thin coating to the hot moulds. A mixture of " Lakol " (10%) + resin (40%) with the addition of 25% of soot was suitable for 800 kg. ingots when applied to moulds at 90–120° C. Molasses with the addition of 25% of aluminium powder was suitable for high-alloy steel and high-speed steel ingots. To eliminate moisture the coating should be applied to the moulds at 150–250° C. Data on the consumption of wash for moulds of different sizes and figures characterising the effect of washes on the ingot surface are given.

Apparent Relations between Manganese and Segregation in Steel Ingots. J. H. Whiteley. (Iron and Steel Institute, 1941, this Journal, Section I.). An examination has been made of the relations of manganese to segregation in all the plain carbon steel ingots which have been examined and described by the Committee on the Heterogeneity of Steel Ingots. As a result the following four tentative conclusions have been reached : (1) The ratio of the manganese increase to that of the sulphur is as a rule higher in sound than in unsound ingots. (2) Carbon, phosphorus and sulphur may all carry some excess of manganese in segregating, their total atomic increments being directly proportional to the percentage increase of manganese in both sound and unsound ingots, although in the latter there is a lesser proportion of extra manganese, owing to gas evolution. The inference is drawn that all three elements exist largely as compounds of iron and manganese in the liquid steel near the freezing point. (3) In sound ingots a linear relationship appears to obtain between the ratio of the incre-

ment of manganese to the total increment of carbon, phosphorus and sulphur and the ratio of manganese to these elements at position E (at the base of the cavity in the ingot head). (4) Segregation is diminished as the ratio of the manganese to the carbon, phosphorus and sulphur in the steel is increased.

Causes of Occurrence of Hairlines in Steel Zh1 and Zh2 for Turbine Blades. V. Speranskiy and A. Koshik. (Stal, 1940, No. 2, pp. 32–38). (In Russian). The presence of non-metallic inclusions in the corrosion-resisting steels $Zh1$ and $Zh2$ (compositions not given) was studied by stepped planing, their presence was related to the occurrence of hairlines, and their constitution was identified by an analytical scheme of etching treatments and by microscopic examination. It is concluded that the occurrence of hairlines is due to the contamination of the steel by non-metallic inclusions which are oxides of the chromite type and by silicate inclusions. Chromites are formed by oxidation in melting, or are introduced with the ferro-chromium. The content of non-metallic inclusions in the latter should be checked. Chromite inclusions are generally crystalline, having been formed from the molten state, whilst the silicate inclusions have a eutectic structure. When many non-metallic inclusions are present and are drawn out by grinding or planing, cracks or hairlines may form at right-angles to them. Variations in the silicon and manganese content as well as that of the other constituents do not affect the occurrence of hairlines. The number of non-metallic inclusions is affected by melting practice, and some recommendations regarding means of obtaining cleaner steel are made.

FORGING, STAMPING AND DRAWING

The Flowability of Different Materials when Die-Forging with a Hammer and with a Press. H. Rauhaus. (Stahl und Eisen, 1940, vol. 60, July 4, pp. 589–599). The author describes an investigation of the relative merits of pressing and drop-forging for manufacturing articles from the following materials : (a) An alloy steel containing carbon 0·32%, chromium 0·68% and nickel 3·47% ; (b) a low-carbon mild steel ; (c) an aluminium alloy containing silicon 0·93%, iron 0·39%, manganese 0·69%, magnesium 0·70%, copper 0·03% and aluminium about 97% ; and (d) a magnesium alloy containing aluminium 6–7%, zinc 0·5–1·0% and magnesium about 92%. A hydraulic press with a working pressure of about 550 tons and a 2-ton drop hammer were used for comparison purposes. The results showed that the flowability of the aluminium alloy was much below that of the steel, but the former could still be worked if

sufficient power were applied. The drop-forging of the magnesium alloy presented difficulties, and it was found that there was a critical rate of deformation beyond which the material would not deform without fracture; this material should therefore only be forged in a hydraulic or similar press. As far as power consumption was concerned, the press was much more economic than the hammer, but as the material cooled much more rapidly when pressing, the limit of deformability was much lower than when hammering; a better-quality product is therefore obtained by drop-forging, especially when a complicated shape is to be produced, in spite of the greater power consumption. Pressing is the most suitable method of producing parts of simple shape. The effects of cooling, die shape, gas pressure in the die and fin formation are discussed.

Discontinuities in Metal Formed during Forging. V. Loshkorev. (Stal, 1940, No. 3, pp. 38–40). (In Russian). Discontinuities of the lamination type are frequently ascribed, quite erroneously, to casting defects in forged blanks. A case is described in which this type of defect was encountered. Billets from rolled rods were used and forged to a rough blank, which was then die-forged. Examination showed that lamination arose during die-forging, and this was ascribed to cracking due to slipping as a result of excessive relative movement (deformation) of portions of the metal in the blank. Tests on a number of steels showed that the appearance of the defect depended to a very considerable extent on the areas of the surfaces coming into contact with the tools. For round or square contact surfaces the ratio of the largest contact surface to the height of the blank had an effect, and it should not exceed 3. Raising the forging temperature tended to diminish the incidence of the defects. The author describes how, in the case of the particular forging, elongating the rough-forged blank in such a way that the axis of the original billet was at right-angles to the longitudinal axis of the blank overcame the defect. For this purpose a billet of much larger diameter was employed.

Forming Stainless Steel Parts for Textile Machinery. F. Westbrook. (Heat Treating and Forging, 1941, vol. 27, Apr., pp. 180–182). The author describes some of the machines and processes used for forming stainless steel sheet up to $\frac{3}{16}$ in. thick into dye gutters and kettles for dyeing textiles.

ROLLING-MILL PRACTICE

Utilisation of Bessemer Steel for some Sections and other Products. S. Loshchilov and B. Fastovskiy. (Stal, 1940, No. 2, pp. 17–32). (In Russian). Experience in the use of Bessemer steel for the rolling and drawing of wire, the rolling of round rod

for bolts, the rolling of angles, the production of corrugated sheet and tinplate, spade blanks and strips for welded tubes is described. In many cases satisfactory results were obtained, whilst in others they could have been obtained by suitable conditions. The ingot quality should be improved, and in this connection convertor practice is briefly discussed.

Exact Rolling. A. E. Lendl. (Iron and Steel, 1941, vol. 14, July, pp. 378–382, 388). The importance of stipulating the exact initial dimensions for the rolling of rounds, squares and flats to exact final dimensions is explained. The application of Eklund's spread formula for the calculation of the lateral spread in passes with non-uniform reduction is shown in several examples. For stipulating the camber of edging passes for flats with parallel and flat lateral surfaces an empirical formula is given and the calculation is shown for several flat sections.

The Filling of Rectangular and Diamond Passes in the Rolling of certain Alloy Steels. M. Vratskiy. (Stal, 1940, No. 3, pp. 24–25). (In Russian). The author describes an investigation of the rolling of the three following steels : (1) A ball-bearing steel containing carbon $1\cdot04\%$, silicon $0\cdot19\%$, manganese $0\cdot30\%$, nickel $0\cdot16\%$ and chromium $1\cdot56\%$; (2) a structural steel containing carbon $0\cdot14\%$, silicon $0\cdot22\%$, manganese $0\cdot35\%$, nickel $3\cdot00\%$ and chromium $0\cdot80\%$; and (3) a silicon steel containing carbon $0\cdot35\%$, silicon $2\cdot56\%$, manganese $0\cdot34\%$, nickel $0\cdot11\%$ and chromium $8\cdot90\%$. For rectangular passes the following expression was deduced : $\gamma = \mu_c (1 - m \tan \alpha)$ where γ is the coefficient of free spreading numerically equal to the ratio of the final to initial width of the stock ; μ_c is the mean coefficient of reduction, α is the angle of grip calculated from the linear reduction and the effective diameter of the roll corresponding to the centre of the pass. The value of the coefficient m was determined for the alloy steels for certain conditions of rolling. When rolling through diamond passes the following expression for the filling of the passes or spreading can be used :
$\gamma = \dfrac{\delta \cdot \mu_c}{\phi \tan \beta/2}$, where γ is again the coefficient of free spreading and numerically equal to the ratio of the final to initial width of the stock measured along its horizontal diagonal, μ_c is the mean coefficient of reduction equal to the ratio between mean height of the stock entering the pass and the height of the pass ; ϕ is the width of the stock entering the pass and β is the value of the obtuse angle of the pass. The value of the coefficient δ was determined for the alloy steels under certain conditions of rolling. δ is a function of the angle of grip α.

Calibration of Rolls for Angle Iron. B. Bakhtinov. (Stal, 1940, No. 4, pp. 19–25). (In Russian). Formulæ are derived which enable the dimensions of the pre- and finishing passes for angle irons to be calculated. Several specimen calculations using the new method are given.

Rolling of Thin Sheets of Transformer Steel. V. Lur'e and L. Podvoyskiy. (Stal, 1940, No. 3, p. 46). (In Russian). The authors discuss the advantages of hot-rolling transformer steel sheets in packs. The steel contained silicon 4·2% and carbon 0·03% max., and the sheets were rolled down to 0·05 mm. thick in packs of 14 to 24 sheets with cover sheets of mild carbon steel. This procedure increased the output of the sheet mill 50 to 100 times as compared with the cold-rolling procedure.

Ultra Finish—What is it? How is it Obtained? H. J. Wills. (Steel, 1941, vol. 108, June 30, pp. 52–54, 86). The author gives some of the definitions relating to surface finish which have been agreed upon by a sectional committee of the American Standards Association. He discusses some of the economic advantages of using rolls with an " ultra " finish which will produce a mirror finish on cold-rolled sheet and strip, and explains some methods of evaluating surface roughness. In conclusion some recommendations are made regarding the maintenance of roll-grinding machines.

The Twisting of the Strip being Rolled Caused by Turning it in Helicoidal Guides. N. Krupnik and Yu. Mayzlin. (Stal, 1940, No. 5–6, pp. 53–56). (In Russian). Helicoidal strip-turning guides cause twisting of steel strip leaving the finishing stand ; the guiding surfaces wear rapidly and, when worn, mark the surface of the strip. The functioning and geometry of the guides are considered and a modified design for the internal contour of the guides capable of adjustment is suggested.

The Effect of Forward Tension and Backward Tension when Cold-Rolling Strip Steel in a Twelve-Roll Cold-Rolling Stand. W. Lueg and F. Schultze. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 7, pp. 93–108). The authors report on an investigation of the effects of different degrees of forward and backward tension on the cold-rolling of steel strip. A small 12-roll stand with working rolls 10 mm. in dia. was used to roll deep-drawing quality strip 15 mm. × 0·5 mm. in section. The results of the forward-tension tests on both lubricated and un-lubricated annealed strip showed that the roll pressure and the mean resistance to deformation, for all degrees of reduction, became less with increasing forward tension. The effect of forward tension was most marked on the low pressures required to produce small reductions, and the effect became less with increasing reductions. The forward slip increased with increasing forward tension. When the forward slip was plotted in relation to the reduction, the curve showed a peak which, with increasing forward tension, shifted towards the higher reduction side of the chart. When rolling pre-rolled strip with forward tension without lubrication, the reduction in roll pressure and the mean deformation resistance were affected in the same way as with soft-annealed strip, but not so strongly. The forward slip was also reduced, but in this case the curves had two peaks, both of which moved in the direction of greater reduction

as the forward tension was increased.   When rolling pre-rolled strip with simultaneously applied backward and forward tension, the effect of the back tension on the reduction of the roll pressure and the deformation resistance was least with small reductions and increased with increasing reduction, so that backward tension had the opposite effect to forward tension.   The effect of backward tension was scarcely influenced by the amount of forward tension applied. Comparing the effects of the two kinds of tension, that of back tension was much more marked than that of forward tension, and this difference increased with increasing reduction.   It was demonstrated, for instance, that with 40% reduction and 20 kg. per sq. mm. forward and backward tension, the reduction in rolling pressure due to the application of backward tension was about three times as great as that attributable to the forward tension.   The amount of forward slip decreased with increasing backward tension.   The results obtained in these practical tests were in conformity with previously published theories on the subject.

The Rolling of Ball-Bearing Sleeves in a Stiefel Mill.   N. Kolpovskiy.   (Stal, 1940, No. 3, pp. 26–30).   (In Russian).   The investigation which was carried out with steel $ShKh15$ containing carbon 1·0–1·1%, manganese 0·26–0·8%, silicon 0·18–0·33%, chromium 1·42–1·45%, nickel 0·13–0·16%, sulphur 0·007–0·010%, and phosphorus 0·013–0·016%, because of the unsatisfactory results obtained when rolling sleeves in a Stossbank mill showed that the billets should be heated slowly to 1150° C. with an arrest at 850–900° C.   The reduction should not exceed 14–15%.   The mandrel for piercing should be positioned in such a way that the formation of the hole occurs at the point of contact between the mandrel and the billet.   The rolling should be finished at a temperature of 900–950° C.   This should be followed by rolling the outside of the tubes in which all deformation should be finished at 850–880° C. The tubes should then be annealed at a maximum temperature of 800° C. followed by holding at 680° and 720° C.   The structure and inner and outer surfaces of tubes produced in this way were satisfactory.

Shell Production by the Witter Process.   S. F. Keener and T. C. Campbell.   (Iron Age, 1941, vol. 148, July 3, pp. 51–53).   The authors describe and illustrate the machinery used for making shells by the Witter process.   This process is a modification of the Assel-mill cross-roll and elongation process, in which a pierced blank forging is rolled and shaped to the dimensions required for machining.   Various sizes of mill are made, and in one of the machines described an average production of 280 75-mm. shell forgings per hour has been maintained for a considerable time.

50 Years of the Mannesmannröhren-Werke.   R. Bungeroth. (Stahl und Eisen, 1940, vol. 60, July 11, pp. 616–617).   The author reviews the history of the development of the Mannesmann process of rolling seamless steel tubes from the efforts of the two Mannes-

mann brothers themselves, followed in 1890 by the formation of the Deutsch-Oesterreichische Mannesmannröhren-Werke, to the present position of this company, which now employs more than 50,000 men.

HEAT TREATMENT

On Decarburization of Steel by Dry and Wet Hydrogen. T. Mochida. (Tetsu to Hagane, 1941, vol. 27, Apr. 25, pp. 260–266). (In Japanese). The author describes his laboratory investigation of the effect on the microstructure of specimens of Swedish steel of decarburising it by passing currents of dry and wet hydrogen over it at temperatures above and below the A_3 point.

Investigation of a Tubular Metal Recuperator. N. Tayts and K. Gannusenko. (Stal, 1940, No. 4, pp. 25–28). (In Russian). The recuperator investigated comprised nineteen $1260 \times 50 \times 3 \cdot 5$-mm. tubes welded to two tube plates. The heating surface was $5 \cdot 845$ sq. m. It was intended for use with small heat-treatment furnaces. All the interior parts were of aluminised carbon steel. The working of the recuperator was investigated under the following conditions : (*a*) Using a constant volume of air and waste gas ; (*b*) with a varying volume of air and waste gas and with the latter at different temperatures. The design was found to be satisfactory. In view of the small pressure loss of the waste gas on passing through the recuperator ($1 \cdot 5$–$2 \cdot 5$ mm. of water) an exhaust fan was not required.

Furnaces for Heat Treating Shells and Guns. F. C. Starr. (Heat Treatment and Forging, 1941, vol. 27, Apr., pp. 190–191). The author briefly describes several types of furnaces used for heat treatment in the manufacture of ordnance. These include rotating-hearth furnaces for shells, furnaces with a link belt conveyor for small cartridge cases, pit furnaces about 25 ft. deep $\times$ 9 ft. inside dia. for gun barrels, and car bottom furnaces for gun carriages and mountings.

A Review of Some Continuous and Batch Type Furnaces. (Wire Industry, 1941, vol. 8, July, pp. 341–345). Descriptions and illustrations are presented of a number of gas-fired continuous and batch furnaces for the heat treatment of wire and strip.

Refinements in Electric Heat Treating. (Steel, 1941, vol. 108, June 23, pp. 82–84). The reorganised heat-treatment department for steel bars up to 25 ft. long at the works of the Bethlehem Steel Co. is described and illustrated. (*See* p. 12 A).

The Formation of " Naphthaline " Fracture in the Heat Treatment of High-Speed Steel. N. E. Lapotyshkin. (Stal, 1940, No. 4, pp. 27–34). (In Russian). A " naphthalene " fracture is sometimes

observed in high-speed steel (see Journ. I. and S.I., 1941, No. I., p. 188 A). Steel in this condition is more brittle and tools have a much shorter life. Previous investigations as to the causes of this condition are discussed. The author has shown that the naphthalene-fracture condition may result from incorrect hot-working and heat treatment. The latter is discussed. The condition arises after repeated quenching. After a first quench, residual austenite receives a critical amount of deformation as a result of volume changes accompanying the martensite transformation. This deformation is enhanced as a result of structural inhomogeneity of the steel. Heating for the second quench causes recrystallisation of the austenite, which forms large grains. The formation of at least 10% martensite is necessary for the development of some degree of naphthalene fracture. A definite relation between the first and second quenching temperatures is also required. The lowest quenching temperatures are 1000° and 1150° C. respectively. Raising the first quenching temperature to 1150° C. lowers the second quenching temperature, but a further increase raises it. The degree of development of the naphthalene-fracture condition increases with increasing holding time. The condition does not develop with holding times of 1 min. at 1260° C. Maximum grain size was obtained after 4 min., but longer holding times (up to 25 hr.) had no further effect. The grain size of the naphthalene fracture increases with increasing cross-section of the specimen.

Heat-Treatment and Properties of Low-Alloy High-Speed Steel EI260. Ya. Dovgalevskiy (Stal, 1940, No. 4, pp. 38–41). (In Russian). The author has investigated the properties of a low-alloy high-speed steel containing carbon 0·85–1·05%, chromium 4·5–5·5%, vanadium 2–2·5% and molybdenum 3–4%; this steel is known as EI260. The effect of changes in the quenching temperature was studied, the optimum was found to be 1220° C. The steel showed some tendency to decarbure. Specimens quenched from temperatures of 1160–1280° C. were tempered for 1 hr. at temperatures of 100° to 600° C. The amount of residual austenite after quenching from 1220° C. was 30–40% and the hardness Rockwell C 59–61. The optimum tempering temperature was 550° C., giving a hardness of Rockwell C 63–64, with 5–10% residual austenite. Tests of steel EI260 in the form of different cutting bits and milling cutters showed it to possess satisfactory cutting properties not sensibly inferior to ordinary high-speed steel.

The Tungsten Situation. J. V. Emmons. (Metal Progress, 1941, vol. 39, Apr., pp. 427–431). After presenting some statistics relating to the production, source and consumption of tungsten in the United States in the period 1910–1940, the author discusses the development, composition and heat treatment of a number of molybdenum high-speed steels. These steels contain from 4% to 9% of molybdenum, small amounts of chromium and vanadium, and about 1·5% of tungsten, and they have been found to have

cutting properties just as good as those of the standard 18/4/1 tungsten-chromium-vanadium high-speed steel.

Study of the Annealing of Cast Iron. T. Takase and K. Nishida. (Tetsu to Hagane, 1941, vol. 27, May, pp. 281–286). (In Japanese). The authors studied the tensile, compressive and transverse strengths, and the hardness, microstructure, density and amount of combined carbon in plain and in nickel-chromium pearlitic cast irons after annealing for 2 hr. at temperatures up to 900° C.

Portable Stress Relieving Controlled Automatically. (Steel, 1941, vol. 108, June 30, pp. 72–74). A description is given of an electric stress-relieving apparatus for use in conjunction with welding. Its principal application is for the welding of pipes and pipe fittings. The heating units consist of resistance wires insulated with refractory beads; these are wound round the pipe at a short distance from the weld, and thermocouples are welded to the pipe one on each side of the joint. For preheating, the heaters are connected to two of the three potentiometer controllers and the pipe ends are brought up to 500° F. For stress relieving, a third thermocouple is attached to the weld and additional heating elements are wrapped round the joint. The temperature is then increased and maintained at the stress-relieving level by the controllers. The usual load is 45 amp. at 220 V.

Unusual Type of Small Parts Hardening Furnace. (Heat Treating and Forging, 1941, vol. 27, Apr., pp. 187–189). A gas-fired heat-treatment furnace and quenching equipment for small parts is described. (*See* p. 12 A).

How to Harden Tool Steels. D. E. Roda. (Iron Age, 1941, vol. 148, July 3, pp. 45–50). The author gives details of the correct heat-treatment, quenching and tempering procedure for the following tool steels : (1) 1·2% carbon steel ; (2) 1·05% carbon steel ; (3) steel containing carbon 0·90% and vanadium 0·25% ; (4) high-carbon high-chromium tool steel ; (5) oil-hardening manganese die steel ; and (6) tungsten-chromium-vanadium high-speed steel (18/4/1).

On the Low-Carbon High Speed Steel. K. Moma. (Tetsu to Hagane, 1941, vol. 27, May, pp. 287–293). (In Japanese). The author studies the mechanisms of the hardening and tempering of low-carbon and high-carbon high-speed steels (0·25% and 0·6% of carbon respectively).

WELDING AND CUTTING

Hard Facing Steel Equipment. F. L. Gray. (Welding Journal, 1941, vol. 20, May, pp. 294–296). The author describes some of the equipment used in a rolling-mill maintenance shop for repairing .

worn wobblers, roller guides and ingot grippers by building up the worn surface and finally applying metal with a welding rod of a hard alloy.

How to Weld 18-8 Stainless Steel. H. H. Moss. (Welding Journal, 1941, vol. 20, May, pp. 297–305). The author describes, with many diagrams and illustrations, the design and preparation of welded joints in 18/8 stainless steel sheet, some types of clamps, the application of flux, the correct adjustment of the blow-pipe flame, the welding technique and the subsequent heat-treatment and grinding procedure.

Welding Stainless Steel for Fighting Aircraft. W. D. Wilkinson jun. (Steel, 1941, vol. 108, June 23, pp. 76–80). The author discusses the suitability of stainless steel for electric resistance, oxy-acetylene and atomic-hydrogen welding. In the construction of aircraft stainless-steel sheet is finding increasing application, and, owing to its relatively high electrical resistance, this material is very suitable for electric spot welding. The welds can be spaced fairly closely. Two welds can be made simultaneously by using two electrodes suitably spaced on one side of the sheet and having a copper backing-up bar on the other side ; with this arrangement, the current passes from one electrode through the sheets to the copper bar, along this bar and back through the sheets to the second electrode.

The Lining of Towers by Stainless Alloy Steels. R. L. Looney. (Welding Journal, 1941, vol. 20, May, pp. 307–310). The author describes how bubble towers in the oil-refining industry can be lined with stainless-steel sheet in order to increase their resistance to corrosion and oxidation. In one instance a tower was lined with 18/8 steel sheets 6 ft. × 2 ft. × 10 gauge electrically welded with $\frac{1}{8}$-in. 18/8 steel electrodes, but the method now recommended is to use strips of 4–6% chromium steel 30 in. × 4 in. × 10 gauge, placed at an angle of 45° to the horizontal with $\frac{1}{4}$ in. between the edges, and to weld them to the wall of the tower by applying three beads with electrodes of 18/8 stabilised steel.

The Welding of Stainless Steel. H. C. Esgar. (Welding Journal, 1941, vol. 20, May, pp. 311–312). The author discusses the welding characteristics of austenitic, ferritic and martensitic stainless steels.

Welding Metallurgy. Volume II. Part IV. Shrinkage. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, May, pp. 315–321). Continuation of a series of articles (*see* p. 101 A). In this part the authors explain the fundamentals of the expansion and contraction of steel under conditions of free movement and under restraint, and apply these principles to a study of the shrinkage stresses and distortion which occur during welding.

Machine Flame Cutting in Preparation for Welding. W. R. Widdoes. (Welding Journal, 1941, vol. 20, May, pp. 292–294). The author describes some of the machines and templates used for the machine flame cutting of parts of very thick steel plate which are subsequently to be welded.

CLEANING AND PICKLING OF METALS

Hot Scarfing of Billets, Blooms and Slabs. E. A. Doyle. (Iron and Steel Engineer, 1941, vol. 18, May, pp. 68–74). The author discusses the development of oxy-acetylene scarfing machines for billets, blooms and slabs. These machines are now installed at some American mills as an integral part of the mill equipment so that the scarfing is incorporated in the regular cycle of operations.

Steel Conditioning. (The Deseaming Process in Particular). D. Taylor. (Journal of the Junior Institution of Engineers, 1941, vol. 51, Part II., pp. 263–271). The author describes the conditioning of steel ingots by planing, square-turning, grinding, chipping and deseaming. The first four processes are dealt with very briefly, whilst the layout of the ingots and oxy-acetylene equipment for deseaming and the advantages of this process are more fully discussed.

Electrolytic Process of Scale Removal from Steel. H. W. Neblett. (American Institute of Electrical Engineers : Blast Furnace and Steel Plant, 1941, vol. 29, Apr., pp. 417–420). The author gives a detailed description of the electrolytic pickling process showing how the plant can be installed in an existing pickling line. He states that the installation of this equipment lowers the cost per ton of steel treated. It will increase the speed of the line regardless of the type of scale, the amount of scale-breaking equipment and the quality of the steel.

Shell Cleaning. M. A. Snell. (Steel, 1941, vol. 108, June 30, pp. 56–59). The author describes two processes for cleaning shell forgings after they have been machined and threaded. The older of the two methods is that of removing the oil and chips by internal and external spraying with a hot alkaline solution ; this method was used twenty years ago, but great improvements in the equipment have been made. The second method is that of degreasing with a solvent such as trichlorethylene. The equipment for both these processes is described and illustrated.

Still Tank Pickling. J. P. A. Roberts. (Iron Age, 1941, vol. 147, May 22, pp. 37–40). In this general discussion of pickling in still tanks the author gives some particulars of bath compositions, describes the functions of inhibitors and gives the United States Navy Department Specification for the requirements of inhibitors.

COATING OF METALS

The Protection of Iron and Steel against Corrosion. J. C. Hudson. (Proceedings of the Staffordshire Iron and Steel Institute, 1939–40, vol. 55, pp. 35–47). The author discusses some of the

recommendations of the Protective Coatings Sub-Committee of the Corrosion Committee (of The Iron and Steel Institute and The British Iron and Steel Federation) relating to painting and metallic coatings for the protection of iron and steel against corrosion. He gives the reasons for the sub-committee's recommendations on cleaning procedure and the choice of paints. In conclusion he outlines the systematic tests which are now being organised with steel specimens coated with seven different metals and alloys, and comments on the value of protective zinc coatings stating that the use of sprayed zinc for protection against marine corrosion is increasing.

Method of Determining the Coating on Sheets. F. G. White. (Blast Furnace and Steel Plant, 1941, vol. 29, May, pp. 509–510). The author presents some tables in which the weights of zinc, tin and tin-lead coatings on galvanised sheet, tinplate and terneplate are related to the coating thickness.

Electrolytic Galvanising is now Possible for Steel Sheet and Strip. (Sheet Metal Industries, 1941, vol. 15, July, pp. 883–884). Some mechanical details of a plant for the continuous electrolytic galvanising of steel sheet and narrow strip are given with special reference to the uncoiling, flattening and coiling mechanism.

Reducing Dross Formation in Hot Dip Galvanising. R. J. Kepfer and L. D. Eubank. (American Hop Dip Galvanizers' Association : Steel, 1941, vol. 108, June 2, pp. 84, 95, 96). The authors report on their investigation of the difference in the amount of dross produced when galvanising pieces of low-carbon steel sheet which have been pre-dipped in zinc-ammonium-chloride solution as compared with similar specimens pre-dipped in dilute hydrochloric acid. Although there was some variation, which depended on the concentration of the solutions used and on the time interval between pre-dipping and galvanising, it was found that, on the average, the amount of iron dissolved by the galvanising bath was about 60% greater when using hydrochloric acid than with zinc ammonium chloride ; in other words, at least 55–60 lb. more dross was formed after pre-dipping with hydrochloric acid.

Hot-Tinning of Steel and Iron. C. E. Homer. (Iron and Steel, 1941, vol. 14, May, pp. 266–268 ; June, pp. 363–365). The author discusses the following aspects of the processes of hot-tinning iron and steel : (1) The effect of impurities such as lead and copper in forming spangled coatings ; (2) sal-ammoniac tinning ; (3) grease tinning of steel ; (4) the contamination of tinning baths by iron : (5) the removal of iron from tinning baths ; (6) the use of tin-lead alloy baths ; (7) the tinning of grey iron castings ; and (8) the correction of the pH values of plating solutions.

The Longitudinal Ridged Structure in the Tin Coating of Tin-plate. B. Chalmers and W. E. Hoare. (Iron and Steel Institute, 1941, this Journal, Section I.). The characteristics of the longitudinal ridge structure in the tin coating of tinplate are described. It is pointed out that similar structures can occur when liquids

other than molten tin are spread on solid surfaces by means of rollers. A physical explanation of the mechanism of formation of the ridge structure is advanced, and this shows that the ridged structure should arise only when the rollers are wetted by the liquid.

It is concluded that the use of non-wetting grease-pot rollers would result in suppression of the ridged structure in tinplate. This has been verified in an experimental tinning machine.

PROPERTIES AND TESTS

(Continued from pp. 134 A–139 A)

Evaluating the Physical Properties of Metals by Means of the Tension Test. C. W. MacGregor. (Sheet Metal Industries, 1941, vol. 15, May, pp. 610–615; July, pp. 877–881). A brief review is made of certain important work which has been carried out relative to the tension test. A discussion is included of various definitions of strain and reduction of area which have been suggested, and these are related to the true values of strain and reduction of area. Approximate expressions are deduced for the true values of strain and reduction of area. Ductility values are examined and two new definitions of tensile ductility are suggested, namely, the true uniform strain and the true local necking strain. Experiments are described in which it is shown that data in conformity with the latter definitions of ductility yield more information on the deformation characteristics of the material than those customarily reported, which are the percentage elongation on 2 in. and the ordinary reduction of area. Experimental results are presented in the form of curves which show the relative values of the various magnitudes of strain and reduction of area along the length of fractured test specimens of various materials. True stress-strain curves are discussed in which the average true stress is plotted as a function of the true strain or true reduction of area. An analytical relationship between the true stress at the maximum load and the average true breaking stress is given and experimental results are included to show the effect of notches on the true stress-strain curves.

On the Origin of the Yield Point of Mild Steel. Kuroda. (Tetsu to Hagane, 1941, vol. 27, Apr. 25, pp. 213–246). (In Japanese). The author puts forward a theory in explanation of the yield-point phenomenon in respect of soft annealed steel.

The Impact Strength of Cast Iron. St. A. Nadaşan. (Giesserei, 1940, vol. 27, July 26, pp. 277–284). The author gives an account of an investigation of the impact strength of 27 different qualities of cast iron in which tests were made by the falling-weight method, the pendulum method, the tensile-impact method, the repeated

impact test and by pendulum tests on cast-iron angles. The impact-bend tests by the falling-weight method showed that the impact-bend strength increased with the static transverse and tensile strengths of the different qualities of iron. The impact strength in the pendulum tests also increased with the static tensile strength with plain specimens; a sharp notch 2 mm. deep decreased the pendulum impact strength by 40–50%; the impact strength of notched specimens of all the qualities tested was practically the same. Tests with square specimens with cross-section areas of 1, 2 and 3 sq. cm. did not reveal any definite relationship between the impact strength and the size; round specimens 8, 10 and 12 mm. in dia. had practically the same pendulum impact strength, whilst that of specimens 17 mm. in dia. was greater. The tensile-impact tests showed that the tensile-impact strength increased with the velocity of the impact, and that the notch-sensitivity increased as the impact velocity decreased.

Investigation of Longitudinal Cracks in the Bottoms of Rails. T. Golubev, K. Bessonov and A. Murzov. (Stal, 1940, No. 5–6, pp. 64–66). (In Russian). Some types of cracks in rails are considered. Those most frequently encountered at the Kuznetskiy Works were due to the opening up of sub-surface blowholes and could be distinguished from cracks caused by rolling stresses, by decarburisation and the marked ferrite network associated with this.

Machine for the Fatigue Testing of Rails. Yu. Grdina and A. Govorov. (Stal, 1940, No. 5–6, pp. 67–69). (In Russian). A short illustrated description is given of a slightly modified Moore type of fatigue-testing machine for rails which was constructed at the Siberian Metallurgical Institute.

Fatigue Tests on Structural Alloy Steels. S. Serensen. (Stal, 1940, No. 3, pp. 31–38). (In Russian). Twelve low-alloy steels with and without nickel were used for the fatigue tests in this investigation. Specimens from one heat of each steel were taken, the steels being supplied in the form of rolled rods. Specimens were subjected to tensile tests, impact tests, bending fatigue tests, torsion fatigue and tension-compression fatigue tests. Apart from smooth test-pieces for the fatigue tests, test-pieces designed to determine the effect of stress raisers (*e.g.*, reduction of cross-section over a short length, transverse holes, screw-threads) were used. The results obtained are given in tabular and graphical forms. The bending fatigue strength of the steels tested increased with increase in tensile strength and reduction in impact strength. This increase was more marked in the absence of nickel if stress raisers were present. Appreciable differences were not observed in torsion fatigue tests and nickel steels of some types were less sensitive to stress concentrations. A screw-thread constituted the most undesirable stress raiser. The advantages and disadvantages of the combinations of different properties in the different steels are discussed and some reference is also made to heat treatment.

Fatigue Tests on Zinc-Coated Steel Wire. D. G. Watt. (Wire and Wire Products, 1941, vol. 16, May, pp. 280–285, 294, 295). In order to study the ability of electric power transmission lines of galvanised steel to resist fracture caused by vibration, a series of tests with a Haigh-Robertson fatigue-testing machine were carried out. The conclusions reached were as follows : (1) Within the limits of tensile strength investigated, namely, 110,000 to 256,000 lb. per sq. in., the endurance limits of zinc-coated wire increased with the tensile strength, whilst the endurance ratio diminished ; (2) the effect of hot-dip galvanising was to lower the endurance limit of patented steel wire by 15·4–28·4% ; (3) reduction by drawing, within the range of wire sizes tested, increased the endurance limits of the wires in both the patented and zinc-coated conditions ; (4) steel wires coated by electrolytic processes had somewhat higher endurance ratios than those coated by hot-dip methods ; (5) hot-dipped wires subjected to reversed bend tests developed closely spaced hairline cracks perpendicular to and terminating at the surface of the steel, whilst no evidence of such cracks could be found in wire coated by electrolytic processes after similar tests ; and (6) lack of uniformity in the test results and the abnormal fractures obtained on defective wire with seams or non-metallic inclusions demonstrated the utility of the fatigue test for detecting faulty materials.

Effect of Burnishing on Fatigue Strength. Parts I. and II. O. J. Horler. (Machinist, 1941, vol. 85, July 26, pp. 154E–156E ; Aug. 9, pp. 170E–171E). The author discusses the effect on the fatigue endurance of steel parts of burnishing, rolling and press-fitting. The method of rolling a bar mounted in a lathe by three equally spaced rollers contained in a cage and acting under spring pressure is described, and diagrams showing the increase of the endurance fatigue limit under torsional loading brought about by rolling are presented.

On Heat Resistant and High Tensile Alloy Cast Iron. T. Saito. (Suiyokwai-Shi, 1941, vol. 10, May 25, pp. 447–464). (In Japanese). The author presents the results of an investigation of the mechanical properties at temperatures up to 600° C. of a variety of alloy cast irons containing additions of silicon, nickel, copper, phosphorus, sulphur, tungsten, molybdenum, manganese, vanadium and chromium.

Reports on Special-Duty Cast Irons. I. Types of Cast Iron. J. G. Pearce. (Institution of Mechanical Engineers : Foundry Trade Journal, 1941, vol. 65, Aug. 21, pp. 121–122, 126). The Research Committee of the Institution of Mechanical Engineers decided that monographs should be prepared to provide engineers and users with information available on special-duty cast irons ; the first of these monographs is now presented. In it the author describes the characteristics of austenitic and martensitic special-duty cast irons, and explains a scheme of classification intended for

the engineering user, rather than the maker. In this scheme the irons are primarily classified as graphite-free, as in the white cast irons, or graphite-bearing, in which the graphite is in one of the following forms : (1) Flake graphite ; (2) temper carbon nodules, characteristic of malleable cast iron ; and (3) very finely divided flakes, regularly distributed and variously named, but sometimes called " super-cooled graphite." The graphite-bearing irons are then subdivided into the ferritic, pearlitic, martensitic and austenitic groups, and the graphite-free irons into the pearlitic and martensitic groups.

High-Duty Cast Irons for General Engineering Purposes. J. G. Pearce. (Second Report of the Research Committee of the Institution of Mechanical Engineers : Engineering, 1941, vol. 152, Aug. 8, pp. 118–120 ; Foundry Trade Journal, 1941, vol. 65, Aug. 14, pp. 105–107). Since the publication of the First Report (see Journ. I. and S.I., 1939, No. II., p. 38 A) the Committee of the Institution of Mechanical Engineers decided to provide engineers with a report on phosphoric irons with the object of assisting in making the fullest use of the national resources in phosphoric ores. In this report the limits to which phosphorus can be used with advantage in engineering castings are indicated ; only plain grey cast iron not specially heat-treated, without alloy additions, and intended for use in the as-cast condition is considered. The effect of phosphorus on the structure, the founding of phosphoric irons, the effect of phosphorus on the mechanical properties at ordinary and at elevated temperatures and on the corrosion resistance of the iron, and the use of phosphoric irons to meet British Standard Specifications are dealt with in turn.

The So-Called Degree of Saturation for Cast Iron. E. Piwowarsky. (Giesserei, 1940, vol. 27, July 26, pp. 285–286). The author considers some of the equations which have been developed for relating the mechanical properties of cast iron to the chemical composition, more particularly to the carbon and silicon contents. Cook has modified Ledebur's formula for the correct relationship between the total carbon and silicon contents and Heyn refers to this modification as expressing the " degree of saturation."

Vanadium in Cast Iron. E. Piwowarsky. (Giesserei, 1940, vol. 27, June 28, pp. 237–245). The author presents a comprehensive survey of the literature on the effect of adding vanadium to cast iron. Vanadium cast irons contain from 0·08% to 0·35% of this element. Vanadium will easily oxidise, and the addition must therefore be very carefully made. It stimulates the formation of carbide, and this effect is the more marked as the silicon and carbon contents of the iron are reduced, the harder the melting furnace is driven and with decreasing thickness of the casting. The structure of the iron is only slightly changed by additions of up to 0·3% of vanadium. With more than 0·3% of vanadium, free carbides of globular shape separate out and there is a tendency to segregate

which affects the castability. Each 0·1% of vanadium increases the temperature at which the formation of temper carbon begins by 30–40° C. The mechanical properties of the ordinary qualities of cast iron are greatly improved by vanadium additions, e.g., the tensile strength is increased by 2–3 kg. per sq. mm. for each 0·1% of vanadium. The mechanical properties of high-duty cast irons are, on the other hand, only very slightly affected. Vanadium undoubtedly decreases the amount of gas in the iron and increases its density. The strength of cast iron at high temperatures, especially between 400° and 500° C., appears to be improved by the presence of vanadium. A study of the freezing points and structures of irons containing different quantities of vanadium showed that the general effect of the element was to shift the iron-carbon diagram to the right. In general it is considered that vanadium is a better substitute for chromium than for molybdenum in cast iron.

Influence of Reduction by Forging and Heat Treatment on the Structure and Mechanical Properties of Steel with and without Additions of Aluminium. S. Shteynberg. (Stal, 1940, No. 2, pp. 26–31). (In Russian). Four 2-ton ingots were top-poured from a basic open-hearth heat of 0·40% carbon steel, additions of 400 g. of aluminium per ton being made in two of the moulds. Two cylindrical forgings with different reductions were made from each ingot. The different forgings were annealed, normalised, quenched and tempered. The microstructure was studied near the surface and near the core of the forgings and samples for mechanical tests were taken from the same regions, the samples being cut in longitudinal and transverse directions. The tensile and impact strengths were determined. The grain size of the aluminium-treated steel in all forgings was smaller. With a few exceptions, the impact strength of all specimens of aluminium-treated steel was higher than that of the plain carbon steel. The aluminium had no effect on the tensile strength. The impact strength of aluminium-treated steel increased with the degree of reduction by forging, whilst the tensile strength was not noticeably affected. The best results were obtained by quenching from 810° C., and tempering at 620° C. Normalising at 830° C. was the next best heat treatment as this increased both the impact and tensile strengths. Annealing at 830° C. slightly increased the mechanical properties of the material near the centre, but lowered those of the material nearer the surface. Anisotropy of impact strength increased with the degree of forging—the impact strength being greater in longitudinal than in tangential specimens. Anisotropy is unaffected by additions of aluminium.

Stainless Steels. S. Hattersley. (Metals Treatment Society of Victoria : Australasian Engineer, 1941, vol. 41, May 7, pp. 10–12, 39, 40). After giving a brief account of the history of the development of stainless steels, the author makes a comprehensive survey of the properties of the various types of heat-treatable and non-heat-treatable stainless steels.

On the Effect of Si, Al and Ti upon the 10% Cr Steel.   Y. Okura and I. Yoshida. (Sumitomo Kinzoku Kōgyō Kenkyu Hōkoku, 1941, vol. 4, Apr., pp. 466–484). (In Japanese).   The authors describe their investigation of the effects of small additions of silicon, aluminium and titanium both separately and in combination on the heat and corrosion resistances and on the mechanical properties of 10%-chromium steels.

Fundamental Studies of Aircraft-Structural Nickel-Chromium Steels. (I.).   T. Ikesima. (Sumitomo Kinzoku Kōgyō Kenkyu Hōkoku, 1941, vol. 4, Apr., pp. 385–418). (In Japanese).   The author reports on his study of the mechanical properties and weldability of alloy steels for aircraft construction which contain carbon 0·3%, nickel 1–5% and chromium 1–3%.

The Fundamental Studies of Silicon-Manganese Steels for the Aircraft Construction. (II).   G. Kozima. (Sumitomo Kinzoku Kōgyō Kenkyu Hōkoku, 1941, vol. 4, Apr., pp. 435–465).   (In Japanese).   The author studies the effect of small additions of chromium, nickel, molybdenum, copper and copper + nickel to steels containing 1% of silicon and 1% of manganese on their mechanical properties and weldability.

Fundamental Studies on Medium Carbon Nickel-Chromium-Molybdenum Steels for Aircraft Materials.   G. Kozima and N. Okusima. (Sumitomo Kinzoku Kōgyō Kenkyu Hōkoku, 1941, vol. 4, Apr., pp. 419–434).   (In Japanese).   The authors study the mechanical properties, hardenability and weldability of a number of steels containing carbon 0·3%, nickel 3–5% and molybdenum 0·5–1·0% which are used in aircraft construction.

The Development of High-Strength Steels for Large Steel Structures in the United States of America.   W. Bischof. (Stahl und Eisen, 1940, vol. 60, June 6, pp. 497–502).   After giving a brief outline of the development of high-strength steels in America from which it is seen that the production grew from a demand by the railway companies for a steel which would reduce the weight of rolling stock, the author discusses and compares the properties of some of the American low-alloy steels with those of the German structural steel St 52.

Tungsten—Its Production and Allied Metallurgical Applications. Part I.   The Production.   E. D. Goss. (Metals Treatment Society of New South Wales : Australasian Engineer, 1941, vol. 41, May 7, pp. 18–19).   The author, after giving some details of the distribution of tungsten-bearing ores throughout the world, describes the preparation of tungstic oxide from a prepared concentrate and the carbon-reduction and hydrogen-reduction methods of producing tungsten from this oxide.   He also gives brief particulars of how ferro-tungsten and cemented tungsten carbide are manufactured.

Tungsten—Its Production and Allied Metallurgical Applications. Part II.   The Application.   N. Pett. (Metals Treatment Society of New South Wales : Australasian Engineer, 1941, vol. 41, May 7,

pp. 19–24, 26, 27). The author discusses the properties and applications of the following types of tungsten steels : (1) A silver steel with 0·91–1·10% of carbon and 0·5–2% of tungsten for making taps, dies and gauges ; (2) finishing steels with carbon 1·20–1·50% and tungsten 3–5% for wire-drawing dies and lathe tools ; (3) shock-resisting steel with carbon 0·40–0·60% and tungsten 1–2·5% for chisels and cold punches ; (4) hot-working steels with carbon 0·25–0·60% and tungsten 8–18% for die steels for hot work ; and (5) high-speed steels containing 14–22% of tungsten for all kinds of high-speed cutting operations.

Medium Alloy Steels. E. S. Davies. (Metals Treatment Society of Victoria : Australasian Engineer, 1941, vol. 41, June 7, pp. 15–16b). The author discusses the heat-treatment characteristics and properties of medium alloy steels which he divides into two groups, one containing one of the alloying elements nickel, chromium, molybdenum and vanadium, and the second containing more than one alloying element ; the second group is subdivided into three sections, namely, the nickel steels, the chromium steels and the manganese steels.

The Properties of Chromium-Nickel-Molybdenum Steel and Results Obtained with Stamping Dies Made of it. P. Orlets. (Stal, 1940, No. 4, pp. 34–37). (In Russian). The properties and effects of heat treatment on three steels falling within the following limits of composition are compared : Carbon 0·50–0·65%, manganese 0·50–0·80%, silicon 0·20–0·37%, chromium 0·50–0·80%, nickel 1·25–1·80% and molybdenum 0·15–0·30%. One steel did not contain vanadium. The second contained 0·15–0·20% of vanadium and to the third the same amount could be added. The beneficial effect of the vanadium additions on the wear of the stamping dies was noted. The higher carbon content necessitates a higher tempering temperature to obtain the same mechanical properties as those of steels of lower carbon content. The optimum hardness for dies depends on their size as well as on the composition of the steel.

Molybdenum-Vanadium High-Speed Steel. M. Braun. (Stal, 1940, No. 4, pp. 37–38). (In Russian). The author reports on an investigation of the cutting properties of the following molybdenum-vanadium high-speed steels which were prepared in a high-frequency furnace :

	(a)	(b)	(c)
Carbon. %	1·9	1·2	1·3
Manganese. %	0·40	0·25	0·40
Silicon. %	0·3	0·3	0·3
Chromium. %	4·2	4·2	4·2
Molybdenum. %	4·0	4·0	3·7
Vanadium. %	3·0	4·0	4·0
Tungsten. %	...	5·0	3·5

Specimens were annealed by holding for 4 hr. at 860° C., cooling to 640° C. in 2 hr., and then cooling to room temperature in air. They

were then forged and quenched from 1220–1280° C. with a resulting hardness of Rockwell C 62–64.   Cutting tools of steels (*a*) and (*b*) were double tempered at 520° C. and tools of steel (*c*) were triple tempered at 500° C. · Cutting tests on alloy steels showed that all three steels were superior to high-tungsten steels in that a higher cutting speed could be obtained ; steels (*a*) and (*b*) were equal and steel (*c*) was superior as regards life to high-tungsten steel.

High-Speed Steels with 7% to 13% of Tungsten.   E. Becker. (Stahl und Eisen, 1940, vol. 60, July 11, pp. 609–613).   The author discusses the results of machining tests with high-speed steels containing different percentages of tungsten.   Planing, rough-turning and drilling tests have shown that the cutting efficiency of high-speed steels is not lowered when the tungsten content is reduced from about 18% to 8–13%.   The latter steels with 2% of vanadium have the highest possible cutting efficiency.   Increasing the vanadium above 2% does not bring the low-tungsten steels up to full efficiency if the carbon content is increased at the same time ; this also applies to high-speed steels containing about 5% of cobalt. With more than 2% of vanadium and a high carbon content the best efficiency is not obtained until the tungsten content is increased to about 13%.   The slightly increased hardening sensitivity of the low-tungsten high-speed steels is not of great importance if great care is exercised in the production and heat treatment of the tools. The author recommends the following composition for a standard high-speed steel : Carbon 0·7–0·8%, chromium 4–4·5%, tungsten 9–12%, molybdenum about 0·7%, vanadium 2% and cobalt 5%.

Steel 9-*KhS* as a Substitute for Tungsten Tool Steel.   N. Yakhonin and A. Ashukhbabov. (Stal, 1940, No. 5–6, pp. 61–64).   (In Russian).   Steel 9-*KhS* contains about 1·5% of chromium, but the full composition is not given.   The optimum conditions of heat treatment were determined, and reference is also made to the cutting properties of the steel.   The life of tools made of steel 9-*KhS* was investigated and found to be superior to that of tungsten tool steels.

British National Specifications for Cast Iron.   J. G. Pearce. (Institute of British Foundrymen : Foundry Trade Journal, 1941, vol. 65, July 24, pp. 59, 60, 64).   The paper on the value of the tests specified for cast iron in British Standards 321 and 786, which appeared originally in pre-print form is reproduced.   (*See* p. 139 A).

METALLOGRAPHY AND CONSTITUTION

From the Microscope to the Electron Microscope.   E. Brüche. (Schweizer Archiv, 1941, vol. 7, Feb., pp. 46–54).   The author gives reasons for the limitations of the magnifying power of the ordinary microscope and explains the development ·and principles of the ·

electron microscope. Some micrographs of magnesium oxide crystals and of the surface of aluminium in the etched and unetched condition are reproduced; that of the etched aluminium is at a magnification of 20,000.

Electrolytic Polishing of Steel Specimens. G. F. Meyer, G. D. Rahrer and J. R. Vilella. (Metals and Alloys, 1941, vol. 13, Apr., pp. 424–430). The authors describe in detail the technique for the electrolytic polishing of carbon steel and stainless steel specimens and discuss the advantages and limitations of this process and that of mechanical polishing. They find that steels containing up to 1·80% of carbon and low-alloy steels can be polished electrolytically with a degree of perfection comparable to that obtained by any mechanical process. Electrolytically polished surfaces may exhibit the following defects : (a) An undulating rather than a flat surface ; (b) high relief of the carbide particles, particularly when these are coarse ; and (c) excessive attack on the non-metallic inclusions, especially in low-carbon steels, which makes the metal appear " dirtier " than it actually is. The amount of preliminary grinding prior to electrolytic polishing is the same as that necessary prior to mechanical polishing. Time is saved, however, by the electrolytic process when the specimens are unusually large, when an excessive amount of metal is disturbed during the preliminary grinding, and if the operator is unskilled at mechanical polishing. The time required for electrolytic polishing after the preliminary grinding is about 10 min. Unless precautions are taken there is danger of the electrolyte (a solution of perchloric acid and acetic anhydride) exploding ; for this reason contamination with alcohol and other organic substances (such as synthetic resin specimen mountings) must be avoided and the ingredients of the solution must be chilled and one added to the other gradually. The ferritic and austenitic stainless steels can be polished electrolytically with a degree of perfection that it is difficult to obtain by mechanical means.

Metallography of Tin and Tin Coatings on Steel. O. E. Romig and D. H. Rowland. (Metals and Alloys, 1941, vol. 13, Apr., pp. 436–443). The authors describe a technique for the polishing and etching of block tin and of sections of hot-dipped tinplate. In the preparation of specimens for the microscopical examination of the iron-tin alloy layer and the tin coating of tinplate great difficulty has been experienced in finding a suitable means of supporting the edge of the specimen. In the method here described, the specimens are dipped separately in bakelite lacquer, dried in air for 30 min., heated for 20 min. at about 275° F. and mounted by bolting up in groups with a strip of cellophane between each. Experience with this method has shown that cross-sections of tin coatings, either hot-dipped or electroplated, as thin as 0·000015 in. can be successfully prepared for photographing. To reveal the iron-tin alloy layer on commercial hot-dipped tinplate, the specimen should be immersed for 1 min., without agitation, in a mixture of

one drop of concentrated nitric acid, two drops of concentrated hydrofluoric acid and 25 ml. of glycerine. For heavy tin coatings and thick alloy layers the specimen should be etched for 3–15 sec., with agitation in a solution containing one drop of concentrated hydrofluoric acid per 100 ml. of absolute methyl alcohol. These agents reveal the tin side of the alloy layer. To reveal the iron side of the alloy layer the above treatment should be followed by etching for 5–10 sec. in 5% picral. A number of micrographs at 2500 diameters of sections of tinplate coatings revealed by this technique are presented.

Experimental Technique in the Study of Alloys by X-Rays. O. S. Edwards and H. Lipson. (Journal of Scientific Instruments, 1941, vol. 18, July, pp. 131–133). The problems encountered in taking X-ray photographs of metals and alloys can be overcome only if several different characteristic radiations are available. Even then it is possible that difficulties may still arise. Various ways of overcoming these difficulties are described, particularly the method of using screens between the specimen and the photographic film, and the use of large cameras. Details for the preparation of targets and of filters for removing the β-radiations are described, and the necessary data for the radiations from fourteen different targets are tabulated.

Random Testing or the Full-Length X-Ray Testing of Welds? E. Brandenberger. (Schweizer Archiv, 1941, vol. 7, Feb., pp. 54–56). From experience in the application of X-rays for detecting defects in welds the author comes to the conclusion that the production of X-ray pictures of the full length of a weld is unnecessary and that X-ray examination at random positions has proved to be quite adequate in practice to ensure the production of good quality welds.

Magnetic-Powder Testing. W. Jaekel. (Giesserei, 1940, vol. 27, July 12, pp. 262–265). The author explains the general principles applied in the magnetic-powder process of testing for cracks and describes and illustrates some of the apparatus used and some accessories of recent design. The latter include water-cooled cables which are attached to a copper bar; this device is used for passing a heavy current through hollow cylindrical bodies in order to test the inner surface for cracks. A travelling sodium lamp for the inspection of shafts with a diffused monochromatic light and an automatic demagnetising appliance are also described.

The Isothermal Transformation of Austenite in High-Speed Tool Steel. (Metallurgia, 1941, vol. 24, May, pp. 22–25). An account is given of an investigation of the isothermal transformation of austenite in two typical high-speed tool steels carried out by A. Gulyaev. The study was made on the lines laid down by Davenport and Bain. The factors studied were : (1) The influence of partial isothermal transformation in the second transformation range upon subsequent martensitic transformation ; (2) the influence of the process temperature on the transformation ; and (3) the influence of the hardening

temperature and of isothermal decomposition at 300° C. on the transformation taking place during tempering.

Equilibrium Diagram of the Ternary Iron-Chromium-Aluminium System (Preliminary Communication). I. Kornilov, V. Mikheev and O. Konenko-Grachova. (Stal, 1940, No. 5–6, pp. 57–59). (In Russian). Alloys containing up to 40% of aluminium and up to 100% of chromium (impurities : carbon 0·02–0·4%, sulphur 0·06–0·1%, phosphorus <0·005–0·006%) were studied along sections parallel to the Fe–Cr and Fe–Al systems, using thermal analysis, microscopic examination and measurements of hardness and electrical conductivity. A melting-point diagram has been constructed. The ternary solid solubility decreased with temperature. The electrical resistance of the ternary solid solution increased with the concentration of chromium and aluminium. Like the electrical resistance of the ternary solid solution, preliminary experiments showed that the resistance to scaling increased with increasing aluminium content for a constant chromium content. The resistance to scaling was affected by the homogeneity of the alloys, being greater in the homogeneous alloys. Thus alloys with 15–25% of chromium and 5–6% of aluminium were more resistant to scaling than alloys with 28–30% of chromium and 5–6% of aluminium.

FUEL

A Laboratory Test for the Ignitibility of Coal. R. A. Sherman, J. M. Pilcher and H. N. Ostborg. (American Society for Testing Materials, 1941, Preprint No. 96). The authors describe an apparatus and procedure developed at the Carnegie Institute of Technology for determining the ignition temperature of solid fuels. The data obtained, principally on bituminous coals, show that variations in the rate of supply of oxygen, in the oxygen concentration, in the rate of heating the furnace and in the packing of the sample, within fairly broad limits, do not materially affect the results.

The Radiation of Carbon Dioxide and Steam with Special Reference to High Temperatures. Parts I., II. and III. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 9–14 ; Oct., pp. 145–153 ; Nov., pp. 207–210). In the first part of this study of the radiation of carbon dioxide and steam the author discusses the radiation of gases on the basis of Plank's law and Kirchhoff's law. In the second part equations for the determination of the radiation of carbon dioxide and steam are developed and calculations of the rates of heat transfer by the radiation of these gases are made. Diagrams are presented expressing the thermal conductivities of carbon dioxide and steam in layers of different thickness for temperatures in the range 700–2100° C. The conclusion reached on the basis of a theoretical study, and in some degree confirmed in practice, is that, especially at very high temperatures (*e.g.*, in the open-hearth furnace, where gas temperatures up to 2000° C. occur), the radiation of carbon dioxide and steam is not so greatly increased that the radiation of the luminous flame is of much greater importance than before. The conclusion that the rate of increase of the radiation of gases decreases at high temperatures stresses the importance of the part played by the gas components which affect the luminosity. In the third part a study of spectroscopic measurements is made, and it is shown that in spite of the increase in the coefficient of absorption and of the effective width of band, the coefficient of thermal conductivity of band radiation rises with increasing temperature from zero to a maximum and then falls back to zero. Above a certain temperature the effect of reducing the thickness of the gas layer is greater than the counteracting effects of increasing the coefficient of absorption and the effective width of band. This preponderating effect of the first factor is apparent in the technical temperature range, as has been proved by total radiation determinations.

The Action of Solvents on Two Indian Coals. R. K. Dutta Roy.

(Records of the Geological Survey of India, 1941, vol. 75, Dec., Professional Paper No. 10). The author gives an account of some extraction tests using benzene, tetralin and pyridine on two Indian coals, one a caking coal from the Barakar measures at Kustore Colliery in the Jharia field, and the other a gas coal from the Raniganj coal measures at Bara-Dhemo Colliery. The results showed that the maximum amount of extract was obtained with pyridine. The residue from the coking coal had no caking tendency.

Carbonizing Properties and Petrographic Composition of Upper Freeport Coal from Morgantown District, Monongalia County, W. Va., and of Lower Freeport Coal from Eastern Indiana County near Cambria County, Pa. A. C. Fieldner, J. D. Davis, W. A. Selvig, D. A. Reynolds, R. E. Brewer, G. C. Sprunk and C. R. Holmes. (United States Bureau of Mines, 1941, Technical Paper 621).

A Study of some Commercial Grades of South Wales Anthracite. D. Hicks. (Fuel in Science and Practice, 1941, vol. 20, June–July, pp. 106–117). The author reports the more important findings of a survey of the whole of the South Wales anthracite field, which was undertaken with the object of determining the availability of fuels suitable for gas producers.

Hydrogenation of High-Volatile Bituminous Coals. L. L. Hirst, R. L. Boyer, A. Eisner, I. I. Pinkel and H. H. Storch. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Aug., pp. 1068–1072). The authors report on the results of some liquid-phase hydrogenation tests carried out at the Bureau of Mines experimental plant at Pittsburgh on high-volatile coals from the Upper Freeport and Black Creek beds, a high-volatile coal from Utah and a high-volatile coal from Indiana No. 4 bed.

PRODUCTION OF IRON

Electric Smelting of Iron Ore. E. Darrer. (Elektrotechnische Zeitschrift : Iron and Coal Trades Review, 1941, vol. 143, Sept. 19, p. 265). Some information is given on the design of Tysland-Hole and of Siemens electric furnaces for smelting iron ore. The power consumption of a modern 8-electrode furnace is about 6500 kW., and it will smelt about 65 tons of rich ore per 24 hr. with a consumption of 2400 kWh. per ton. These values are entirely dependent on the working conditions, the quality of the pig iron made, and the type of coke and ore used. Electric-furnace smelting is limited to those few areas where cheap hydro-electric power is available, hence its development in Scandinavia.

Dehydrator Removes Moisture from Blast-Furnace Air. (Steel, 1941, vol. 109, Aug. 18, pp. 74–76). A brief description is given of a cleaning and dehydrating plant for treating blast-furnace blast. One year's experience with the plant has demonstrated that it has great flexibility. After filtering, the air passes through coils of tubing which either heat or cool it, depending on the setting of a dry-bulb controller in the outlet air. The moisture is removed in a contact chamber in which Raschig rings are held in place by two parallel open-mesh screens; the air passes horizontally and the dehydrating salt solution drops vertically. The plant includes a regenerator for bringing the diluted solution up to the correct concentration.

The Valuation of the Charge for the Production of Pig Iron in the Blast-Furnace. H. Bansen and E. Krebs. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 91–103). The authors develop and explain the practical application of a method of determining the economic value of a blast-furnace charge by a simple calculation based on the chemical composition. In this method a " standard charge " is used as a basis and the cost and composition of its components, i.e., the iron, the companion elements, the additions and the gangue, are determined. The economic value of a component is obtained by multiplying the quantity by its cost, and the sum of these products represents the total economic value. Values for coke can be determined in a similar manner. Given these economic values, it is then possible to calculate the optimum composition of the charge for the reduction of given ores.

British Standard Specification for Portland-Blastfurnace Cement (Not Exceeding 65% Blastfurnace Slag). (British Standard Institution No. 146–1941).

Powder Metallurgy. I. Stewart. (Machine Shop Magazine, 1941, vol. 2, Sept., pp. 102–106). In this general discussion of powder metallurgy the author deals with the advantages and limitations of the process, the availability of metal powders, their physical characteristics, the power required for compression and the heat treatment during and after the pressing process.

FOUNDRY PRACTICE

Melting Furnaces for Grey Cast Iron. H. H. Shepherd. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Sept. 11, pp. 171–172). The author reviews a report compiled by the Melting Furnaces Sub-Committee of the Institute of British Foundrymen on Melting Furnaces for Grey Cast Iron.

The various melting media are dealt with in five chapters on crucible, air, electric, rotary and cupola furnaces respectively, with a concluding chapter on melting costs.

On the Melting of Cast Iron at High Temperatures and the Hot Blast Cupola. (Nippon Kinzoku Gakkai-Si, 1940, vol. 4, Dec., pp. 418–448). (In Japanese). The design of cupolas and blast heaters is discussed, and the effect of high casting temperatures on the structure and mechanical properties of the iron is surveyed.

Small Diameter Cupola Practice. W. Pola. (Australian Institute of Foundrymen : Foundry Trade Journal, 1941, vol. 65, Aug. 28, pp. 143–144, 146 ; Sept. 4, pp. 155–157). The author describes how a small cupola at an Australian foundry is lined, charged, controlled and tapped. The use of tuyere dampers is discussed and their application to small cupolas is advocated ; when the blast is shut off from one tuyere at a time, the blast entering the other tuyeres forces hot gases and flames across to the one shut off ; this causes all cold slag and splashes of metal to be melted away. By using the dampers in rotation it is seldom necessary to use a bar to poke the tuyeres clear.

Quick Malleable Cast Iron. H. Tanimura. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 860–864). (In Japanese). The author discusses the influence of nickel and copper on the preparation and properties of malleable cast iron.

On the Application of Walkenried Sand for Steel Castings. F. Roll and E. Offermann. (Giesserei, 1941, vol. 27, Aug. 9, pp. 301–305). The authors describe a laboratory investigation of the properties of a moulding sand from Walkenried-Ellrich in the Harz district and some trials in the foundry. From the data obtained a sand specification for moulds for steel castings was established.

The Drying of Cores. J. Küpper. (Giesserei, 1940, vol. 27, Aug. 9, pp. 297–301 ; Aug. 23, pp. 321–324). The author points out how paying full attention to the correct drying of cores can contribute to a reduction in the number of rejected castings and to reduced cleaning costs. He describes some tests on the strength of cores dried at different temperatures, and reproduces time-temperature curves of the temperature changes in the core oven. A number of different types of core-drying equipment are described and illustrated, and some recommendations on the transport of cores from the core shop to the oven are made.

Mould Construction and Tackle. E. Longden. (Iron and Steel, 1941, vol. 14, Aug., pp. 411–413 ; Sept., pp. 433–434). Continuation of a series of articles (*see* p. 165 A). In the first part the author describes and illustrates the moulding technique for the production of gas- and oil-engine pistons, steam cylinder covers, impellers and plain cylinders. In the concluding part the making of the pattern, cores and mould for large carding cylinders for textile machinery is described.

Canadian Foundry Operates Mechanized Shop. P. Dwyer.

(Foundry, 1941, vol. 69, June, pp. 51, 135–138; July, pp. 62, 107–110). The author gives an illustrated account of the re-organised foundry of the Canadian Westinghouse Co. at Hamilton, Ontario. To meet the demands for a greatly increased production the layout of the existing floor space was completely rearranged, sand-handling equipment and roller conveyors were installed, and a system of continuous pouring was introduced; this enabled the production to be increased by about 50% without enlarging the existing buildings.

PRODUCTION OF STEEL

The Manufacture of High-Quality, Low-Cost Steel. Basic Steel-making Practice. P. J. McKimm. (Steel, 1941, vol. 109, Aug. 11, pp. 87–90, 106–108). In this general discussion of modern steel-making practice the author refers to a special design of open-hearth furnace called the " Bosshardt " furnace, in which 18/8 stainless is being successfully produced. This furnace is characterised by the extremely high built-up air-uptakes at each corner, the very steep slope of the ports and the complicated arrangement and layout of the four gas-ports. Some statistics relating to the composition of the steel produced, of the furnace atmosphere and of the slag are presented. The author also comments on the increased use of a refractory for open-hearth bottoms which has the following approximate composition: MgO 30%, CaO 55%, Fe_2O_3 11%, Al_2O_3 1–2% and SiO_2 3–4%.

Production of Mild Steel in the Acid Open-Hearth. F. Eisermann. (Iron and Coal Trades Review, 1941, vol. 143, Aug. 29, pp. 183–184; Sept. 5, p. 212). An English translation is presented of the author's paper on the theory and practice of the acid open-hearth process. This paper appeared originally in Stahl und Eisen, 1940, vol. 60, July 18, pp. 629–633 (see p. 74 A).

Some Late Developments in Open-Hearth Steel Practice. D. L. McBride. (Metal Progress, 1941, vol. 39, June, pp. 717–720). In discussing open-hearth practice the author points out the advantages of working basic furnaces with hot metal low in silicon. He refers to Wheaton's paper (see Journ. I. and S.I., 1940, No. II., p. 182 A), in which it is shown that reducing the silicon in the hot metal reduces the amount of lime required and the time for refining. The technical difficulties resulting from desiliconising and desul-

phurising treatments of blast-furnace iron, especially that of skimming off the siliceous or caustic slag before delivering to the mixer, are then dealt with. The author refers to the conclusion of Fetters and Chipman (*see* Journ. I. and S.I., 1940, No. II., p. 53 A) that the degree of oxidation of the bath is more completely controlled by the carbon content than by the residual manganese or any of the slag components, and believes that the application of this will lead to a close control of deoxidation practices for rimming, semi-killed and killed steels.

Use of Amorphous Graphite in the Open-Hearth Shop. R. J. Zemanek. (Steel, 1941, vol. 109, July 14, pp. 71–74). A shortage of pig iron is making itself felt in the United States, with the result that many open-hearth furnaces are now melting charges of 100% steel scrap. In the present paper the author describes the practice of adding Mexican graphite to the charge to supply the requisite carbon. In acid open-hearth practice the furnace bottom may be covered with light scrap before charging the graphite, or it may be charged directly on the furnace bottom. It is recommended that the charging box be filled one-third full with borings; these should be covered with some 100-lb. bags of graphite, and the box should then be filled up with borings; this procedure reduces the loss of carbon by oxidation. At least 70% recovery of the carbon is obtained. In basic open-hearth practice, the graphite should be covered with lime to obtain the best results.

Proceedings of the Twenty-Fourth Open-Hearth Conference. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, Apr. 23–25, 1941). The Twenty-Fourth Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers was held at Chicago with L. F. Reinartz as the General Chairman. The key-note of the conference was " increasing production for national defense."

The first paper to be presented was one for which the author, H. J. Forsyth, gained the McKune Award; this dealt mainly with the effect of tarring ingot moulds on the surface condition of billets of killed steel; in the second part of this paper statistics were given showing the relation between the number of times a mould has been used and the time spent in scarfing the resulting billets. The session on open-hearth refractories was opened by L. A. Smith, who observed that in the efforts to increase production no attempt to increase the overall heating surface of checkers in regenerators was being made, but some general improvement was attained with bigger flues and less regenerative capacity. He observed that there was a little more interest taken in the insulation of furnace roofs, but there was not much actual development, furnace builders preferring to keep to known methods and materials. The increased use of basic bricks in place of silica bricks for front walls was noted and this seemed to be a paying proposition. P. M. Reinartz then read a paper on " Crespi " dolomite bottoms,

but gave little technical information on their construction. The next topic for discussion was monolithic linings for open-hearth furnace doors. A. Lilly gave particulars of some experiments on furnaces at the works with which he is connected, stating that although the cost of the monolithic door was about eight times that of one made of firebricks, the former lasted about 270 heats and the latter for only 12 to 20 heats. R. H. Stone then introduced the subject of graphite *versus* clay ladle stoppers, and stated that steel pourers who have been accustomed to clay stoppers do not appreciate how much pressure can be exerted when closing a graphite stopper. E. E. Callinan explained the motion-film method of studying nozzles and teeming procedure, in which the cinema film is exposed at the high speed of 1500 to 1600 pictures per sec., whilst the projection speed is only 24 per sec. This technique is quite new, and no conclusions have yet been drawn from a study of the films. The insulation of open-hearth furnaces was the next item to be discussed, and the experiences of various members were put forward. It was stated that the roof insulation could be left on too long, and that 185–200 heats was the correct life in some cases. Various members then gave their views on checker design and cleaning checker bricks. H. S. Robertson presented a paper entitled " Adequacy of Furnace Refractories Supplies," in which he reviewed the position of the supply of refractory bricks to American steelworks and showed that the increased demand would be met without great difficulty.

The second session was concerned with strategic minerals in open-hearth steel production for defence needs. This was opened by C. H. Herty, jun., who considered the manganese problem and pointed out that a survey had shown that the manganese consumed in strip and sheet manufacture was greater than that consumed for bar steels. He also discussed the technique of adding spiegel and ferro-manganese in steel-making, and German investigations on the conservation of manganese. The next strategic mineral to be discussed was chromium, and J. H. McDonald presented a short paper entitled " Use of Chrom-X as Replacement for Ferro-Chrome." Chrom-X contains about 50% of chromium as against 67–70% in ferro-chrome, and is added to the ladle or the mould. This subject was followed by that of iron and steel scrap. E. C. Barringer presented a paper entitled " Requirement for and Supply of Iron and Steel Scrap," a survey of the scrap situation in the United States, with many statistics; it was shown that the demand greatly exceeded the supply and that lighter and cheaper grades of scrap will have to be used in increasing quantities. This concluded the session. At the Annual Fellowship Dinner, E. D. Martin presented an address on " The Steel Industry's Contribution to Our National Defense Effort," and this was followed by C. B. Randall on " Defense in Steel; and Steel in Defense."

The second day's session commenced with a paper by J. Stapleton

on "How to Make Low-Silicon, Low-Sulphur, High-Temperature Basic Iron," in which the author concludes that, whilst desulphurising with soda ash is most economical when considering the blast-furnace process only, desiliconising with mill-scale or flue-dust may prove to be the most economical when including the open-hearth practice, because in the latter case the temperature of the iron is approximately 80° F. higher. This paper was followed by one on the production of low-silicon basic iron using mill-scale additions, in which the author, P. R. Nichols, described the technique for adding about 7000 lb. of mill scale to a 50-ton ladle of iron, which reduced the silicon from 0·96% to 0·49% and the manganese from 1·89% to 0·85%; from the data presented it is seen that the process is not only a success metallurgically, but also from a cost standpoint. The next paper was by J. R. Brady, on the use of desiliconised hot metal in the basic open-hearth furnace, in which it was shown that the use of mill-scale to desiliconise the hot metal definitely increased the production of steel without detriment to its quality. The desulphurisation of hot metal was the next subject for discussion. In this connection C. L. Labeka and J. E. Walker presented a paper entitled "Desulphurization of Molten Iron with Soda Ash and Effect of Desulphurized Hot Metal on Open-Hearth Practice and Steel Quality"; the authors' general conclusion was that desulphurising the hot metal with soda ash had no adverse effect on the subsequent open-hearth operations.

The second annual meeting of the Acid Division of the Open-Hearth Conference took place on the second day; no papers were presented, the proceedings comprising an open discussion, under the chairmanship of G. S. Baldwin, of a great variety of subjects of practical interest to acid open-hearth operators.

In the session on basic open-hearth operations, the following papers were read and discussed: "How to Increase Open-Hearth Production by Better Planning," by G. L. Danforth, jun.; "Oil-Fired Open-Hearth Flame Radiation," by A. J. Fisher; "Automatic Control of Open-Hearth Furnace Operation," by C. N. Arnold; "Extending the Use of Automatic Controls," by E. H. Cauger; "Automatic Control of Open-Hearth Furnace Operations," by H. V. Flagg; "Developments in Furnace Construction," by B. C. Hutchinson; and "Better Construction—Building a 'Balanced' Furnace," by H. C. Barnes.

The final session dealt mainly with steel-furnace slag reactions and slag control. J. Chipman discussed some points mentioned in an earlier paper by himself and K. L. Fetters on the reactions between slag and metal (see Journ. I. and S.I., 1941, No. I., p. 206 A). This was followed by a paper entitled "Evolution of an Open-Hearth Slag," by H. J. Sweeney. The use of optical pyrometers for measuring bath temperatures was discussed by H. A. Parker, and the procedure for making a 0·50% carbon shell steel to a given analysis was described by J. H. McDonald.

Hydrogen Equilibria in Steel Making. P. Herasymenko and P. Dombrowski. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 109–115). The authors describe a method of obtaining samples of the gases evolved from molten steel for making hydrogen determinations. They then present and discuss some results of hydrogen determinations made while making steel in an electric furnace and in acid and basic open-hearth furnaces. In the electric-furnace process the hydrogen content fluctuates considerably during the oxidation period and then shows a marked increase during the reduction period, at the end of which the hydrogen content lies in the comparatively narrow range of 4–6 c.c. per 100 g. of steel. Hydrogen curves for the basic open-hearth furnaces showed that the hydrogen content is not related to the vigour of the boil. The authors do not agree with the statement frequently appearing in the literature that the hydrogen content of molten steel can be reduced by a vigorous boiling, as they have found that, depending on the conditions, vigorous boiling sometimes raises and sometimes lowers the hydrogen content. A method of determining the hydrogen in acid and basic open-hearth slags is also described. The hydrogen content of molten steel is expressed by the following reactions :

$$Fe + 2H^+ \rightleftharpoons Fe^{++} + 2H$$
$$Mn + 2H^+ \rightleftharpoons Mn^{++} + 2H$$
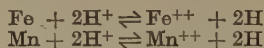
and the authors arrive at the following equation for the equilibrium constant of the second reaction in the temperature range 1550–1650° C. :

$$k\frac{Mn}{H} = \frac{[H]}{(H)} \sqrt{\frac{(MnO)}{[MnO]}} = 3 \cdot 97 - 0 \cdot 0164\ (t - 1550)$$

which is applicable to both the acid and basic processes. In conclusion some experiments to determine the hydrogen distribution in 4-cwt. forged ingots of chromium-nickel steel and the effect of hydrogen on the occurrence of flakes are described ; from these it was established that, for forgings of the size used, the lowest hydrogen content at which flakes were observed was 4·0–4·8 c.c. per 100 g. of steel.

Contribution to the Metallurgy of Manganese by Thermo-Chemical Measurements and Equilibrium Calculations. H. Ulich and H. Siemonsen. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 27–34). The authors describe how they determined the heat of formation of the oxides of manganese, manganese carbonate and manganese carbide and the application of the data obtained to calculate the following equilibria : (a) Between the manganese oxides and carbon-monoxide/carbon-dioxide mixtures ; (b) between the manganese oxides and hydrogen and steam mixtures ; (c) between manganese carbide and carbon-monoxide/carbon-dioxide

mixtures; and (d) between iron carbide and manganese carbide in steels containing up to 10% of manganese.

Large Electric-Arc Furnaces—Performance and Power Supply. B. M. Jones and C. M. Stearns. (Electrical Engineering, 1941, vol. 60, July, pp. 763–769). The authors describe an investigation of the load surges on two 25-ton Héroult 3-phase electric-arc furnaces supplied by a 10,000-kVA. transformer. Following the installation of the second furnace, a test was made with both furnaces melting down simultaneously at the highest secondary voltage. The load surges of the two furnaces were found not to be additive, and the net peak for the two furnaces was only 20% higher than that of the first furnace.

The Comparison of Separate Units of a Combine. W. Grenz. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Dec., pp. 293–304). The author explains the principles to be applied in making comparisons of the economic results achieved by the different units of an iron and steel combine.

ROLLING-MILL PRACTICE

Some Examples of Deformation without Machining. A. Eichinger and W. Lueg. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 47–52). In this mathematical treatise the authors endeavour to develop fundamental equations for cold-deformation processes which involve no increase in width, and discuss their application to the drawing of flat bars and to the cold-rolling of strip.

Faultless Rolling. A. E. Lendl. (Iron and Steel, 1941, vol. 14, Aug., pp. 405–407). The author studies the causes of cracks in the surface of steel which are attributable to the rolling mill. The first group of faults discussed is that caused by the mechanical parts of the mill, such as the roller tables, guides, strippers and the condition of the roll surface, and the second group consists of those caused by the reduction during rolling. It is shown how the source of some of the cracks of the first group can be traced by taking samples and quenching them in order to remove scale, by watching the various passes and by upsetting tests. Faults in the second group are due to wrong calibration; examples of this type of fault in the square-oval-square and the diamond-square sequences of rolling are described.

Factors that Influence Grinding Rolls for Ultra-Finish Work. H. J. Wills. (Steel, 1941, vol. 109, July 21, pp. 56–60). The

author makes recommendations on the technique of grinding rolls for producing rolled products with a high-quality surface finish. The selection of a grinding wheel with the right grit and bond, and the correct relation between the grinding wheel speed and the roll speed are most important. For ultra finish (*see* p. 173 A) the roll speed should be as high as possible, without causing vibration. In making the finishing pass the ratio of the traverse to the roll speed should be as low as possible, with not more than 0·25 in. traverse per revolution of the roll, and the grinding wheel should not be allowed to move more than a quarter of its width off the roll at the end of its traverse.

How to Avoid Specific Blemishes when Grinding Ultra-Finish Rolls. H. J. Wills. (Steel, 1941, vol. 109, Aug. 11, pp. 92–96). After discussing the technique of roll-grinding (*see* preceding abstract), the author, in the present article, describes and illustrates the effects produced on the roll surface by the chattering of some part of the grinding machine, by building vibration, by incorrect alignment of the wheel and work, a dirty cooling medium and other causes, and shows how these faults can be eliminated.

Conditions for Obtaining a Clean Surface on Sheets of 18/8 Stainless Steel. B. Shapiro. (Stal, 1940, No. 5–6, pp. 43–46). (In Russian). The calibration of rolls for the rolling of square billets of 18/8 stainless steel, and subsequently slabs, is first considered. In this connection a determination of the spreading of stainless steel when rolled at temperatures of 950–1050° C. was made to ensure that the passes should be completely filled, as incomplete filling had caused concave sides which, on cross-rolling, had given rise to surface films. Alloy-surface-hardened rolls should be used, as plain cast-iron rolls wear rapidly and cause surface roughness. The atmosphere of the heat-treatment furnace should be slightly oxidising and the temperature should be 1100–1150° C. Preliminary pickling should be done in a 5% solution of nitric acid (sp. gr. 1·4) to loosen scale. This is followed by dipping in a bath at 50–60° C. containing 47·5% of hydrochloric acid (sp. gr. 1·19) and 5% of nitric acid (sp. gr. 1·4), remainder water. For the best corrosion resistance, stainless steel sheets must finally be subjected to cold-rolling. The cold-rolling practice is considered.

Centralised Lubrication for Heavy Machinery. F. J. Taylor. (Iron and Steel, 1941, vol. 14, Aug., pp. 408–410). The author discusses the design of centralised lubrication systems for oil and for grease for the forced lubrication of heavy machinery such as that used in rolling-mills.

Develops Floating Drive for Mill Runout Tables. J. D. Knox. (Steel, 1941, vol. 109, Aug. 25, pp. 70–72). The author describes a new design of drive for the rolls of mill run-out tables where each roll is driven by a separate motor. The motor armature is mounted on a sleeve, and this sleeve is keyed to the roller shaft. Both the shaft and the armature are carried on the same set of ball bearings,

with the result that the two are always in line, even when the roller is bent by radiated heat, or moved by the heavy pieces passing over it.

Investigation of the Forces on the Shears of the Zaporozhstal Slabbing Mill. A. Tselikov, A. Iroshnikov and A. Gurevich. (Stal, 1940, No. 5–6, pp. 47–53). (In Russian). The shears at the Zaporozhstal rolling mill were intended to cut slabs with a maximum cross-section of 200 × 1500 mm., the maximum pressure being 2000 tons. The investigation was made using oscillographic recordings of the current and voltage taken by the motors and the number of revolutions. The analysis of the oscillograms is discussed. Allowance was made for frictional losses in the driving mechanism. The results are given in tabular and diagrammatic form, the latter showing especially the cutting stress in kg. per sq. mm. of the original cross-section plotted against the relative depth of penetration of the shears, and also the cutting stress at different temperatures. The cutting-stress/relative-penetration curves showed well-pronounced peaks ; the maximum values of the stress decreasing very considerably with rise in temperature, whilst at the same time the position of the maximum was shifted to lower values of relative penetration owing to the increased ductility of the metal. It was difficult to determine a relation between the tensile strength and the cutting stress. Under similar conditions the maximum cutting stress of a low-alloy chromium-copper steel exceeded by 25–30% that of plain carbon steels. The maximum pressures with the thickest slabs used (200 × 1500 mm.) were only of the order of 1000 tons, *i.e.*, only half of the design load of the shears. It was, therefore, possible to shear larger slabs for which flame-cutting had previously been employed.

Determination of the Optimum Production Rate and Proportioning of Products in Rolling-Mills. A. M. Wolter. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 77–85). The author explains how the cost per ton of producing different shapes and sections in a rolling-mill working at the optimum rate of production varies with the section, and describes a method of making up rolling programmes which will ensure that the mill is producing at the lowest possible cost per ton.

Standard Order Forms for Rolled Steel and the Possibility of Applying them to the Planning of Work in Rolling-Mills. F. Petzold. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 549–553). The author describes the standard order forms and the procedure for transmitting orders for rolled steel which have been adopted by German rolling-mills. He also shows how these forms can be used in the compiling of daily rolling programmes.

HEAT TREATMENT

The Heat Treatment of Grey Iron. F. Fleischer. (Giesserei, 1940, vol. 27, Aug. 23, pp. 317–321). The author discusses the mechanism of the tempering of grey cast iron, giving several examples of the hardness and strength properties obtained on tempering plain and alloyed cast irons at different temperatures.

Automatic Camshaft-Hardening Machine. (Engineering, 1941, vol. 152, Sept. 5, p. 186). An illustrated description is given of a fully automatic hardening machine which applies the Shorter flame-hardening process to the hardening of automobile engine camshafts.

On the Mechanism of Decarburization of Iron and Steel. I. Naito. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, Jan., pp. 25–34). (In Japanese). The author describes an investigation of three examples of the decarburisation of steel and cast iron. In the first the distribution of the carbon in an austenitic steel decarburised at above 900° C. was observed. In the second the irregular distribution of carbon in a white cast iron after decarburisation was explained by the theory of the diffusion of carbon. The third example was that of the decarburisation of steel at below 900° C.

New Heat-Treating Gas Prevents Surface Decarburization. (Steel, 1941, vol. 109, July 14, p. 68). Brief particulars are given of a protective atmosphere for scale-free hardening, bright-annealing and sintering. It is known as " Drycolene," and as it contains carbon monoxide, no decarburisation of the surface being treated can take place. The producer for this gas consists of a retort into which charcoal is fed ; this retort is heated by coke-oven gas, natural gas, propane or butane, mixed with air, and the products of combustion are passed through the incandescent charcoal, where further reactions take place, producing the " Drycolene." The producer is available in two sizes supplying 200 and 750 cu. ft. per hr.

New Completely Automatic Furnace Equipment Heat Treats Munition Shells Scale-Free. W. F. Ross. (Heat Treating and Forging, 1941, vol. 27, June, pp. 293–296). The author presents an illustrated description of a continuous gas-fired heat-treatment plant for the heating, oil-quenching and tempering of 3-in. shells at the rate of 150 per hr. The interesting feature of this plant is the conveying equipment ; this consists of ten heat-resisting alloy tubes passing right through the hardening furnace and down into the quenching medium at the discharge end. The shell forgings are placed end-to-end in these tubes, and hydraulically operated pushers working at controlled time intervals push them through the heating-up and holding zones. The tubes are also kept filled with a protective atmosphere and, as the discharge ends are sealed

by the cooling oil, the shells are never exposed to the air while in the oxidising temperature range. A high efficiency is claimed for this type of furnace, as there are no heat losses to trays, bogies, walking beams or other types of conveyor.

The Bright-Annealing of Cold-Rolled Deep-Drawing Quality Steel Strip in a Continuous Furnace. A. Pomp and G. Niebch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 8, pp. 121–136). The report of an investigation of the suitability of the continuous furnace for annealing cold-rolled, deep-drawing quality steel strip is given. An account of this work has also been published in Archiv für das Eisenhüttenwesen, 1941, vol. 14, Oct., pp. 179–186 (see p. 11 A).

Troubles with Cracked Methanol as an Atmosphere for Heat Treating. E. C. Roglin. (Metal Progress, 1941, vol. 39, June, pp. 693–696). When using cracked methanol as a protective atmosphere at temperatures in the 1550–1820° F. range in heat-treatment furnaces, it was found to have a slightly carburising effect in some cases and a decarburising effect in others. In the present paper the author describes some research work on the reasons for this behaviour. It was established that the different conditions under which the methanol was cracked affected the behaviour of the products. Methanol begins to crack at below 500° F., but cracking is not complete below about 1400° F. The tests described were carried out on samples of 0·15% carbon steel, 0·75% carbon tool steel and an alloy die steel with 0·35% of carbon. When held at 1820° F. in methanol cracked at 1820° F. all three steels were badly decarburised. With a cracking temperature of 1550° F. and the specimens held at 1820° F. for 36 hr., the tool steel was decarburised and the other two were carburised. The atmosphere produced by cracking the methanol at 1590–1600° F. proved to be almost neutral for the die steel at 1820° F. The important conclusion to be drawn from this investigation is the necessity of producing heat-treatment atmospheres under definitely controlled and readily reproducible conditions.

Heat Treatment of Forgings. A Large Gas-Fired Installation. (Iron and Steel, 1941, vol. 14, Aug., pp. 425–427). An illustrated description is given of a new gas-fired heat-treatment plant for small forgings (see p. 12 A).

How an English Plant Obtained an 81 per cent. Increase in Annealing Furnace Output. R. Trautschold. (Steel, 1941, vol. 109, Aug. 18, pp. 97–98). The author describes a plant for annealing steel strip and wire at a South Wales works where a greatly increased output was obtained by improving the system of control. The plant consisted of two sealed cylindrical Grunewald furnaces, one for preheating and the other for finish-annealing, heated by burning blast-furnace gas and air in a muffle surrounding one furnace, and leading the products of combustion round the other furnace, and thence to the stack. The temperatures were previously

controlled by a conventional on-and-off potentiometer regulator. This system was changed to a proportionating-type controller system, manipulated by a sensitive modulating valve, which maintained a fairly constant flame length, together with a pneumatic time-programme controller system and the necessary auxiliary instruments for fully automatic operation.

On the Influence of Time on the Softening of Cold-Rolled Deep-Drawing Quality Steel Strip by Annealing. A. Pomp and G. Niebch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 8, pp. 109–119). The authors report on an investigation of the effect of short-time annealing on the strength and structure of cold-rolled steel strip, the object being to ascertain whether annealing for periods of up to 3 min. would be satisfactory, as this is the approximate heating period for strip passing through a continuous annealing furnace. The specimens were of 0.06% carbon steel in strips $200 \times 40 \times 1$ mm., series of which were cold-reduced 10%, 20%, 40% and 60% before annealing. The annealing times were 1, 1·5, 2, 2·5 and 3 min., and the temperatures were 650°, 700°, 750°, 800°, 850° and 900° C. The strips which had been reduced 40% and 60% were fully annealed at furnace temperatures of 650° C. after 2·5 min., 700° C. after 2 min., 750° C. after 1·5 min., and at 800°, 850° and 900° C. after 1 min. Extending the annealing time at any of these temperatures had no further effect on the strength properties. The tensile strengths and the elastic limits were up to 7% greater than those of strip which was long-time annealed on an industrial scale. Specimens of the latter are referred to as works samples. The structure of specimens annealed at 650° and 700° C., as well as that of those annealed for the shorter periods at higher temperatures, were the same as that of the works samples ; longer annealing times at the higher temperatures caused recrystallisation and the development of cementite. The specimens which had been reduced 20% were fully annealed after 3 min. at 650° C., 2·5 min. at 700° C., 1·5 min. at 750° and 800° C., and 1 min. at 850° and 900° C. In this case also prolonging the annealing did not cause any further change in the strength properties. All specimens annealed at under the A_3 point attained the same tensile strength and slightly greater elongation than that of the works samples, whilst the elastic limit and the ratio of the elastic limit to the tensile strength were considerably lower than those of the works samples. The grain size of the former was slightly coarser than that of the latter. The specimens which had been reduced 10% had to be heated to 800° C. for 2 min., 850° C. for 1·5 min., and to 900° C. for 1 min. to be fully annealed ; the strength properties were practically the same as those of the specimens which had been reduced 20% ; the grain size became distinctly smaller even before these specimens were dead soft.

The investigation proved that a low-carbon strip steel which gained strength as a result of cold deformation would lose it again

after a very short period in an annealing furnace. With annealing temperatures below the A_3 point, the time necessary for fully annealing is shorter as the degree of reduction is increased, but this does not apply if the temperature is above the A_3 point. It therefore seems probable that cold-rolled, deep-drawing quality steel strip can be successfully annealed by a continuous process in which the annealing time would be only a few minutes.

A Practical Guide to the Heat Treatment of Stainless Steels. G. B. Berlien. (Steel, 1941, vol. 109, Aug. 4, pp. 74–76). The author describes the correct forms of heat treatment for hardening and for annealing the straight chromium and the 18/8 stainless steels.

On the Direct Electric Resistance Heating and the Dilatometrically Controlled Automatic Quenching of the Stainless Steel Turbine Blade. N. Kawashima and Y. Tobita. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 876–884). (In Japanese). The authors describe a method of heat-treating 13%-chromium stainless steel turbine blades in which the blade is heated by passing a heavy current through it. The quenching temperature is determined indirectly by a dilatometric apparatus which automatically cuts off the heating current when the blade has expanded by an amount corresponding to the correct quenching temperature. The method is very rapid and there is no scaling or surface decarburisation.

Induction-Hardened Cylinder Bores. F. P. Peters and E. F. Cone. (Metals and Alloys, 1941, vol. 13, June, pp. 713–722). The authors describe a form of induction-hardening equipment for the hardening of the internal surface of cylinders and other hollow bodies. This equipment comprises a source of high-frequency current (usually a motor-driven inductor alternator) and its metering, conducting and transmitting accessories ; the hardening machine with its heating head, quenching fixture and work-holding device ; and the controller system. The hardening apparatus is connected to a sliding-core switching transformer with a cable. The load is applied by moving the transformer primary coil into inductive relation with the secondary coil, the latter being connected to the heat-treating head with a massive conducting arbor similar to the spindle of a machine tool. This arbor consists of two concentric copper tubes insulated from each other. The transformer is at the top of the hardening machine, with the arbor and heating head suspended from it. A suitable holding fixture is provided for each job, and in some cases the part being treated is rotated and simultaneously moved axially with respect to the heating head. This head comprises a copper tube coiled round a laminated iron core ; as the tube has to carry very heavy currents, cooling water is circulated through it. The quenching device is attached to the lower section of the machine and moves upwards directly under the heating head. All the movements of the head, the cooling device and the part to be treated are maintained by a sequencing

controller made up of a series of cam-operated switches. This form of machine (known as the Budd machine) has been successfully used in a production line for the rapid hardening of the inside of automobile rear wheel hubs, cast-iron Diesel-engine cylinder liners and steel aero-engine cylinder barrels. The complete hardening cycle, which is precisely reproduced as often as desired, requires only a few seconds, and a surface hardness of up to Rockwell C 69 can be obtained. It is also claimed that parts hardened by this process are more easily machined than parts of equal hardness produced by other processes. A metallurgical examination of cast-iron cylinder liners hardened by the Budd process has revealed that there is a considerable amount of austenite retained in the hardened zone. This austenite is revealed by X-ray and magnetic methods, but is not recognisable under the microscope ; it must therefore be of ultra-fine grain, and its presence may account for the machinability of metal of such high hardness.

Diesel Cylinder Liner Bores are Induction Hardened. (Steel, 1941, vol. 109, July 21, pp. 62–65). A brief illustrated description is given of the process and equipment used for the induction hardening of the internal surface of cylinder liners. (*See* preceding abstract).

Quenching Media for Heat Treating such Items as Alloy Steel Gun Forgings. A. F. Macconochie. (Steel, 1941, vol. 109, Aug. 25, pp. 68, 87). The author gives some information on the comparative rates of cooling of steel specimens of equal dimensions in brine, tap water and a number of mineral and vegetable oils, and discusses the suitability of these quenching media.

Oil Temperature Control in Quench Baths. (Iron and Steel, 1941, vol. 14, Aug., p. 428 ; Wire Industry, 1941, vol. 8, Aug., pp. 399–400). A description is given of a cooler for cooling the oil in quenching baths. The cooler consists of a galvanised welded sheet steel casing mounted on a shallow steel water-tank. Inside the casing is a bank of steel coils, through which the oil is circulated by a pump. A second pump lifts water from the tank in the base and forces it through atomising nozzles at the top of the cooler ; from these nozzles the water falls in a fine rain down the inside of the cooler and over the outside surface of the cooling coils.

WELDING AND CUTTING

Welding Metallurgy. Volume II. Part VI. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, July, pp. 432–439). In the sixth part of this series (*see* p. 178 A) the authors discuss at length the weldability of a large number of alloy steels

and the metallurgical principles on which predictions as to weldability are based.

Weldability—Weld Metal Cracks. W. Spraragen and G. E. Claussen. (Welding Journal, 1941, vol. 20, July, pp. 289-S–304-S). The authors present a comprehensive review of the literature up to July 1, 1939, on cracks in weld metal. A bibliography with 136 references is appended.

The Relation of Microstructure to Appearance of Fracture as Found in the "Nick-Break" Test of Welded Plate. H. W. Sharp. (Welding Journal, 1941, vol. 20, July, pp. 306-S–309-S). The author describes an investigation of the type of fracture obtained by the "nick-break" test on welded plate. Specimens of $\frac{1}{2}$-in. and 1-in. steel plate were used ; the ends of the welds were nicked to a depth of about $\frac{1}{4}$ in. and the specimens were broken by impact. An examination of micrographs of the metal deposited in the first pass and that of subsequent passes showed that the former, which had a silky appearance to the naked eye, had undergone some grain refinement and that the fracture ran along the grain boundaries. The metal of the other passes had a coarser structure and here the fracture was transcrystalline.

Investigation of the Single Bead Weldability Test. A. W. Manlove. (Welding Journal, 1941, vol. 20, July, pp. 324-S–328-S). The author investigated the application of the single-bead weldability test (developed at the United States Arsenal at Watertown) to two plain carbon steels (carbon 0·20% and 0·45% respectively). This weldability test consists of depositing a single bead of weld metal 3 in. long down the centre of a plate $9 \times 3 \times \frac{1}{2}$ in., sectioning the plate transversely at a distance of 1 in. along the bead from its starting point and making a hardness survey of the heat-affected zone ; if at any point the hardness exceeds Brinell 350, the steel is not readily weldable under the conditions of the test. The author carried out this test on a number of plates by making seven sections $\frac{1}{2}$ in. apart across the bead and plate. The conclusions reached were : (1) The hardening effect at the starting end of the bead was negligible, the effect at the five positions between the ends was relatively constant, and the maximum effect was obtained under the end where welding finished ; (2) neither lengthening the plate to 9 in. nor widening it to 6 in. caused any appreciable difference in the hardness readings ; (3) an increase in the plate thickness from $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. caused an appreciable increase in the hardness ; and (4) the changes in temperature of the bottom surface of the plate could not be used as an indicator of the hardenability of the heat-affected zone.

Comparison of the Properties of 18/8 Weld Metal, Cast Metal and Rolled Metal. K. W. Ostrom and R. D. Thomas, jun. (Welding Journal, 1941, vol. 20, July, pp. 317-S–323-S). It is pointed out that electric welding is a casting process, and that when two sheets are welded together the joint represents cast metal fused into rolled

metal. In order to provide information relating to this aspect of welding, the authors studied the microstructure of 18/8 stainless steel in its various forms and after different heat treatments and correlated the structures to the mechanical and corrosion-resisting properties. Specimens were prepared from ingots as cast, from hot-rolled ingots, from weld metal as deposited from coated 18/8 electrodes and from hot-rolled weld metal, and these four groups of material were tested in four conditions of heat treatment. The following conclusions were indicated by a study of the test results : (1) An annealing treatment lowers the tensile strength slightly and increases the ductility ; (2) at an annealing temperature of 1950° F. or higher all carbides dissolve, and will remain in solution if the metal is quenched to room temperature ; (3) precipitation of the carbides which is known to occur between the temperatures of 900° and 1400° F. is found in all samples which have not been annealed ; by heat-treating at 1200° F. for 4 hr. the carbides are precipitated at phase boundaries ; (4) the metal is more subject to corrosion if the carbide precipitation is around fine grains than if around coarse grains ; (5) ferrite which is formed by rapid cooling from the molten state is not readily dissolved by ordinary annealing treatments ; (6) the presence of ferrite does not appreciably affect the resistance to nitric acid attack ; and (7) stainless steel cast by arc welding will respond to heat treatment in the same manner as in cast ingot form ; the differences in the corrosion resistance of the two forms of metal are due largely to the amount of carbides present.

Effect of the Alloying Elements on the Structure and Weldability of Steel St 52. W. Bischof. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 519–526). The author reports on an investigation the purpose of which was to determine the effect of the presence of manganese, silicon, chromium and copper on the hardness of the heat-affected zone when welding 50-mm.-thick plates of steel St 52. When more than 1% of manganese was present there was a marked increase in the hardening, whilst the effect of chromium was not so great. An increase in the silicon and copper (within the limits specified for steel St 52) had no effect. It was established that the hardness obtained on quenching this steel bore no relationship to the hardening of the heat-affected zone on welding. Specially prepared samples of fine-grained and of coarse-grained steel St 52 were used as the parent metal for the bend test on weld metal (see Journ. I. and S.I., 1940, No. I., p. 244 A) ; the coarse-grained specimens broke almost without deformation after bending through a very small angle, whilst the fine-grained specimens could be bent through 60° with good deformation. The general conclusions reached were : (1) The weldability of steel St 52 cannot be improved by changing the composition ; (2) the best weldability was obtained after heat treatment which produced a fine pearlite-ferrite structure ; (3) fine cracks will occur when welding the steel if the section is thick and if the structure is coarse ; and

(4) the bend test on weld metal is of practical value in the testing of this steel.

The Cause of Welding Cracks in Aircraft Steels. J. Müller. (Welding Journal, 1941, vol. 20, July, pp. 309-S–316-S; Sheet Metal Industries, 1941, vol. 15, Oct., pp. 1299–1305). This is an English translation of a paper which appeared in Luftfahrtforschung, 1940, vol. 17, Apr. 20, pp. 97–105. The author gives an account of the investigations and the method adopted in Germany to prevent the occurrence of cracks in gas-welded aircraft steels up to about 3 mm. thick. The conclusion arrived at was that neither the welding technique nor the design of the weld was the fundamental cause of welding cracks, but the composition of the steel. Experience and investigations over the last eight years have shown that the tendency for welding cracks to develop in unalloyed as well as in some low-alloyed steels is caused principally by too much sulphur or too much phosphorus in the steel. As a result of this the German Air Ministry in 1936 ordered a reduction in the permissible amounts of sulphur, phosphorus and carbon in their chromium-molybdenum steel No. 1452 to 0·015% max., 0·020% max. and 0·27% max. respectively. This measure led to a marked decrease in the occurrence of welding cracks.

Stainless Steel in Aviation. C. de Ganahl. (Welding Engineer, 1941, vol. 26, May, pp. 25–28). The author describes some of the spot-welding machines used by an American company manufacturing aircraft for welding petrol tanks and wing panels of stainless steel sheet.

Forgings *versus* **Welded Assemblies.** J. A. Petrie and G. W. Papen. (Metals and Alloys, 1941, vol. 13, June, pp. 734–736). The authors describe the difficulties encountered in making a fulcrum (part of an aeroplane landing gear) by a welded steel assembly, and state why it was eventually found to be more economical to re-design the part and make it of forged aluminium.

Manual and Machine Flame Grooving. E. V. David. (Welding Journal, 1941, vol. 20, July, pp. 417–428). The author presents a comprehensive description, with numerous illustrations and diagrams, of the equipment and technique for cutting grooves in steel plate and for preparing the edges of steel for welding with the oxy-acetylene torch by hand and with a machine.

CLEANING AND PICKLING OF METALS

Descaling Shell by Abrasives Blasting. J. D. Alexander. (Steel, 1941, vol. 109, July 14, pp. 52–53). The author describes a new type of machine for cleaning the inside and outside surfaces of shell forgings (*see* p. 17 A).

Determination of the Pickling Time for Steel Bars with the Aid of Calculations of the Magnitude of the Influencing Factors. E. Nowak and H. Stevens. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 43–46). The authors investigated how the time required for the pickling of steel bars is influenced by the following factors : (1) The sensitivity of the material to pickling ; (2) the pickling procedure ; (3) the concentration of the pickling agent ; (4) the surface condition of the material ; (5) the section of the bars ; and (6) the annealing treatment which the bars have been given. Equations are derived for these factors and a nomogram for the rapid determination of the pickling time for a ton of bars under given conditions is presented.

COATING OF METALS

(Continued from pp. 179 A–181 A)

A Practical Discussion of Zinc-Iron Alloys. W. G. Imhoff. (Wire and Wire Products, 1941, vol. 16, July, pp. 383–387, 408–410). The author relates the galvaniser's experience of dross formation to the theory of the formation of zinc-iron alloys. Experiments are first described which proved that no trace of dross or zinc-iron alloy could be detected when chemically pure zinc, pure rolled zinc sheet, and good quality zinc containing 0·08% max. of iron were melted and held at the temperature of a hot-dip galvanising bath. The solubility of iron in zinc, and the formation and characteristics of crystals of zinc-iron alloys which constitute the dross, with special reference to the influence of temperature changes, are discussed in conclusion.

The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers. Part II. T. P. Hoar, T. N. Morris and W. B. Adam. (Iron and Steel Institute, 1941, this Journal, Section I.). Further statistically planned canning experiments of the type described in Part I. of this series of papers (*see* Journ. I. and S.I., 1939, No. II., p. 55 P) have been carried out with a pack of Czar plums in double-lacquered cans, and with packs of white cherries, gooseberries, Pershore plums and prunes in plain cans. It is shown that for such packs of Czar plums and gooseberries, cans made from low-phosphorus/high-copper steel-base tinplate, recommended in Part I. for six other packs, are to be preferred from the point of view of hydrogen-swell formation, and that the cathodic efficiency of the steel for hydrogen evolution has a significant influence on the rate of swell-formation for such packs of cherries, gooseberries and prunes.

Two new types of corrosion test for the steel base are described :

The first, consisting of immersion in actual fruit juice, gives very poor correlation with the rate of hydrogen-swell formation within a can; the second, consisting of a very short immersion in boiling dilute hydrochloric acid, gives surprisingly good correlation. Reasons for these results are advanced, and the design of a rational steel-base test is discussed.

Differences between lacquered- and plain-can packs, and between fruits, are discussed in the light of the present and previous work.

Bituminous Coatings. A. O. Beckman, R. M. Badger, E. E. Gullekson and D. P. Stevenson. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Aug., pp. 984–990). The authors describe a number of methods of investigating factors affecting the corrosion of metals protected by bituminous coatings. Apparatus is described with which the mechanisms of osmosis, the diffusion of water and of various electrolytes, and the penetration of water through small holes or fissures could be examined. It was observed that the penetration of water through a bitumen diaphragm due to osmosis, absorption or adsorption was negligible.

Enamel and Paint Finishes over Sprayed Metal. E. E. Halls. (Metal Treatment, 1941, vol. 7, Summer Issue, pp. 50–54, 57). The author discusses the value of enamel and paint coatings on steel sheet which has been sprayed with zinc by the wire-pistol process. The results of a series of exposure tests lasting one year showed that ordinary organic finishes applied to sprayed zinc surfaces are quite satisfactory and that no pretreatment such as phosphatising is necessary. In conclusion the author makes recommendations on the layout of a painting and enamelling shop.

PROPERTIES AND TESTS

A Deflectometer for Transverse Testing of Cast Iron. C. T. Greenidge and E. C. Kron. (Metals and Alloys, 1941, vol. 13, June, pp. 723–725). The authors describe an apparatus for making transverse bend tests on cast iron and automatically recording load-deflection curves. The specimen rests on two supports on the moving head of the testing machine, the stationary head being fixed at the centre of the upper side of the specimen. The deflectometer itself consists essentially of a tube through which a rod slides. A shoe is fastened to the base of the sliding rod and a second shoe is fixed to the tube. This tube is attached to the moving head, and therefore rises with it as the upward load is applied. The rod is held by a spring against the under side of the specimen opposite the stationary head, and the rod therefore remains stationary until the specimen is broken. The increasing distance between the shoes

on the rod and on the tube is a measure of the deflection. The device used to record the deflection consists of two steel wedges moving horizontally in grooves in the shoes. The wedge used for recording purposes is pulled between the shoes by a line wrapped round a recording drum, and a weight is suspended on it to move the wedge into the increasing gap and to rotate the drum. As the wedge has a slope of 1 in 10, the linear movement of the drum is 10 times the deflection of the bar. The load-recording arm geared to the dial of the testing machine moves outward as the load increases, and the combined movement of the arm and drum produce the load-deflection curve. The apparatus requires only one operator, and very accurate results have been obtained with it.

Young's Modulus of Elasticity and some Related Properties of Graphitic Materials. H. A. Schwartz and C. H. Junge. (American Society for Testing Materials, 1941, Preprint No. 40). The authors report on an investigation of the elasticity, density, electrical resistivity and coercivity of ingot iron, steel with carbon 0·45%, a nickel-chromium-molybdenum steel, a nickel cast iron, Meehanite, malleable cast iron, white cast iron and a graphitisable steel. An extremely close correlation between the density and Young's modulus was observed, this being closer than that between the graphitic carbon content and Young's modulus.

On the ΔE-Effect of Iron, Nickel and Cobalt. M. Yamamoto. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, May, pp. 167–174). (In Japanese). The author discusses the changes in the Young's modulus of electrolytic iron, decarburised 0·1% carbon steel, electrolytic nickel and electrolytic cobalt in magnetic fields up to 900 oersteds.

Effect of Specimen Shape and Size on Measured Values of Tensile Properties. G. F. Jenks. (American Society for Testing Materials, Report of Committee E-1 on Methods of Testing, 1941, Preprint No. 2, pp. 8–12). The author reports on an investigation of the tensile strength of three brands of low-alloy steel plate of five thicknesses using flat specimens $\frac{3}{4}$ in. and $1\frac{1}{2}$ in. wide and round specimens 0·357 in., 0·252 in. and 0·178 in. in dia. in order to test the effect of specimen shape and size. There was no appreciable difference in the tensile strength values obtained for the two widths of flat specimens. The tensile strength per square inch was greatest for the $\frac{5}{8}$-in. thick plate and decreased with decreasing plate thickness. It was observed that the influence of the specimen shape was extremely small when $L/\sqrt{A} = 4·5$, where L is the gauge length and A is the area of the cross section. The A.S.T.M. rules for the tensile testing of steel to various specifications are also discussed.

Effect of Rate of Strain on Yield Strength, Tensile Strength, Elongation and Reduction of Area in Tension Tests. P. G. Jones and H. F. Moore. (American Society for Testing Materials, Report of Committee E-1 on Methods of Testing, 1941, Preprint No. 2,

pp. 13–16). The authors present the results of tensile tests on specimens of steels S.A.E. 1045 and 1020, copper, duralumin and brass, using a 100,000-lb. Olsen screw-power machine at six different speeds of head representing the rates of strain which can be obtained on ordinary testing machines. The test results are shown by curves and are compared with those obtained in a previous investigation in which an oscillograph was used (*see* Journ. I. and S.I., 1941, No. I., p. 219 A); the two sets of results are in close agreement and prove that reliable determinations of rates of strain can be made without elaborate special apparatus.

The Stress-Strain Characteristics of Cold-Rolled Austenitic Stainless Steels in Compression as Determined by the Cylinder Test Method. R. Franks and W. O. Binder. (American Society for Testing Materials, 1941, Preprint No. 30). The authors describe a method of studying the stress-strain characteristics in compression of cold-rolled stainless steel from 0·01 to 0·06 in. thick. The specimens consisted of strip or sheet cold-formed into cylinders with a diameter/thickness ratio such that when tested in compression they failed symmetrically to the axis. The 17/7 stainless steels had a better resistance to compression applied in the direction of rolling than had the 18/8 steels, particularly when the steels were cold-rolled to give a tensile strength exceeding 150,000 lb. per sq. in. A low-temperature (200–300° C.) stress-relieving heat treatment improved the compression-resistance of both these stainless steels.

The High-Velocity Test. K. Iokibe and S. Isida. (Nippon Kinzoku Gakkai-Si, 1940, vol. 4, Dec., pp. 408–417). (In Japanese). The authors describe an impact testing machine which they designed for fracturing specimens at a velocity higher than that attained in Izod and Charpy machines and some tests carried out with it on specimens of boiler steel, high-manganese steel and stainless steel.

Impact-Torsion Tests of Heat-Treated Tool Steels. M. Itihara. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, May, pp. 188–192). (In Japanese). The author describes an investigation of the impact-torsion strength of ten different tool steels tempered at various temperatures.

The Strain Hardening of Gray Cast Iron. J. S. Peck. (American Society for Testing Materials, 1941, Preprint No. 39). The author studied the effect on the hardness of specimens of grey cast iron produced by applying compressive loads increasing by increments of 10,000 lb. per sq. in. Specimens 1 in. square and ½ in. high were used. The test data showed that with loads up to about 40,000 lb. the hardness (measured by taking Rockwell tests on each of the four faces) increased slightly. From 40,000 to 60,000 lb. no significant change was noted, whilst above 60,000 lb. the hardness decreased rapidly. The cause of this apparent violation of the strain-hardening theory was investigated by preparing micrographs; these showed that minute cracks appeared after loading at 60,000 lb. and these cracks increased with succeeding loads until failure

occurred. It was concluded that the penetrator of the testing machine slipped into one of these minute cracks, thus giving a lower reading.

Slaty Fractures in Steels Caused by Crystalline Segregation. W. Eilender and R. Pribyl. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 35–42). The authors describe and discuss the slaty form of fracture which is sometimes observed in steel which has been subjected to deformation, and investigate the influence of the melting procedure, the deoxidation and the conditions of solidification on the tendency of steel to fracture in this manner. The tendency is promoted by the existence of a layer of non-metallic impurities, by shrinkage holes, by gas holes which have not welded up and by irregular structures formed as a result of segregation. Fracture due to crystalline segregation is the form most frequently met with, and this is caused by the different precipitation velocities of a non-uniform martensite. Superheating the melt has a favourable effect in suppressing the tendency of steel to fracture in this manner. The fracture tendency of chromium-nickel and chromium-molybdenum steels is discussed, and it is shown that crystalline segregation in heat-treatable chromium-nickel steels greatly increases their solubility in hydrochloric acid.

Bending-Fatigue Tests on Heat-Treatable and Case-Hardening Chromium-Molybdenum Steels in Comparison with Nickel-Bearing Steels. A. Pomp and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 10, pp. 149–168). The authors present the results of 161 series of bending-fatigue tests on plain, notched and drilled specimens of heat-treated chromium-molybdenum steels, case-hardened chromium-molybdenum and chromium-nickel steels, and nickel-bearing and nickel-free steels. The test data are given in tables, and the effects of tempering, specimen size, notches and holes on the fatigue strength are shown by curves. No definite relationship between the fatigue strength and the tensile strength could be established, but in the tensile strength range of 70–150 kg. per sq. mm. an approximate relationship between the fatigue strength and the type of specimen was found.

The Behaviour of Cast Iron and Malleable Cast Iron under Alternating Stresses. A. Pomp and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 11, pp. 169–201). The authors present a report of their investigation of the fatigue strength of plain, drilled and notched specimens of a number of cast irons and malleable cast irons by the Wöhler process. From the data obtained curves showing the bending-fatigue strength, the tension-compression fatigue strength and the damping capacity of the various qualities of iron were constructed. With all the qualities of iron tested by the tension-compression method, increasing the mean compression load increased the values obtained for half the stress range; but with torsional

fatigue tests on malleable cast iron increasing the mean stress caused only a slight change in the value for half the stress range. In tension-compression tests with a high mean compression load, the fractured surface of the cast-iron specimens was at an angle of between 80° and 40° to the direction of the applied load, whereas with the malleable cast iron it was perpendicular to the direction of loading; in the latter case the zone of fatigue fracture could be distinguished from that of the final fracture. The torsional fatigue strength of the malleable cast iron, whether annealed or not, and whether machined or as-cast, was about 1·5–3·0 kg. per sq. mm. higher than the tension-compression fatigue strength (with zero mean stress). Bending-fatigue tests on flat cast-iron specimens showed that the ratio of the fatigue strength of drilled specimens to that of plain ones was in the range 0·50–0·78. The ratio of the tension-compression to the bending-fatigue strength of plain specimens of six different cast irons was 0·35–0·58, whereas for steel the ratio was 0·50–0·96.

The Effect of Shot-Blasting and Its Bearing on Fatigue. J. M. Lessells and W. M. Murray. (American Society for Testing Materials, 1941, Preprint No. 31). The authors report on an investigation of the effect of shot-blasting on the fatigue strength of quenched and tempered steels and of cold-worked steels. From the experimental data presented it is concluded that under certain conditions a considerable increase in the fatigue life and endurance limit of steel is brought about by shot-blasting. This was true for all the steels tested, but for steels having high residual stresses due to quenching and inadequate tempering, the increase in the endurance limit was not always in evidence.

Fatigue Comparison of 7-in. Diameter Solid and Tubular Axles. O. J. Horger and T. V. Buckwalter. (American Society for Testing Materials, 1941, Preprint No. 32). The authors describe an investigation of the fatigue strength of American rolling-stock axles about 7 in. in dia. of steel containing carbon in the range 0·37–0·52%; both solid and hollow axles were tested and the effect of press-fitting a wheel in lowering the fatigue resistance of axles after several different forms of heat treatment was examined. It was shown that some hollow axles had a greater fatigue resistance than solid axles and that flame-hardening of the wheel-fit portion of the axle greatly improved the fatigue strength.

Fatigue and Static Load Tests of a High-Strength Cast Iron at Elevated Temperatures. W. L. Collins and J. O. Smith. (American Society for Testing Materials, 1941, Preprint No. 38). The authors report the results of fatigue and static tensile tests on notched and plain specimens of a high-strength cast iron containing nickel 0·20%, chromium 0·31% and copper 0·37%. Very little difference was noted between the static tensile strengths of plain and of notched specimens (with a circumferential V groove) at any temperature in the range 70–1100° F. The endurance limits of plain

specimens and of specimens with a small transverse hole were determined by reverse bend tests at seven temperatures in the range 70–1200° F., and were found to be practically equal at each temperature, provided that the net cross-sectional area was used in calculating the stress for the drilled specimens. The ratio of the endurance limit to the tensile strength was also constant at 0·44 for the entire range of temperature.

The Effect of Type of Testing Machine on Fatigue Test Results. (American Society for Testing Materials, Report of the Research Committee on Fatigue of Metals, 1941, Preprint No. 25). A report is submitted by the Research Committee on Fatigue of Metals of the A.S.T.M. on an investigation of the endurance limit of metals as determined by several different types of machine. The following types of fatigue-testing machine were employed : (1) Rotating-beam machines ; (2) rotating-cantilever-beam machines ; (3) vibratory flexural machines ; and (4) direct axial tension-compression machines. Specimens were prepared from duralumin, from a heat-treated nickel-chromium-molybdenum steel of high strength and from a nickel-molybdenum steel of medium strength. Many of the S-N (stress/number-of-cycles) curves are reproduced and the endurance limits of each of the three materials as determined by the different types of testing machine are compared.

A New High-Temperature Fatigue Machine. W. P. Welch and W. A. Wilson. (American Society for Testing Materials, 1941, Preprint No. 34). The authors describe a machine for making rapid determinations of the endurance limit of metals at temperatures up to 1000° F. The machine is of the fixed-cantilever, constant-deflection type, designed primarily for the application of alternating bend stresses to the specimen, which is of generous size and easily machined. The specimen is stressed at a frequency of 120 cycles per sec. and at a constant amplitude by a reciprocating electro-magnetic motor. The results of operating experience over a period of a year and some test data obtained with the machine are reported.

Testing Material in the Resonance Range. R. K. Bernhard. (American Society for Testing Materials, 1941, Preprint No. 35). In order to simulate service conditions there is a demand for testing machines with which dynamic fluctuating loads can be applied either alone or superimposed on a constant load. In the present paper the author describes a machine for making these tests which is designed for testing large specimens and riveted or welded structural units. The power input required is quite low, because the principle of working at or near resonance frequencies is applied.

Ultrasonics. (Metallurgist, 1941, vol. 13, June, p. 26). The development of applied ultrasonics as a technique for the testing of metals is briefly reviewed, and reference is made to some of the foreign technical literature on this subject.

Wear of Caterpillar Shoe and its Pin. N. Yamamoto. (Nippon

Kinzoku Gakkai-Si, 1941, vol. 5, Feb., pp. 60–68). (In Japanese). The author reports on an investigation undertaken to discover a suitable wear-resisting alloy steel to replace the nickel-chromium steel used for pins for manganese steel caterpillar shoes.

Testing Pneumatic Chisel Steels. E. K. Spring and J. K. Desmond. (Iron Age, 1941, vol. 148, Aug. 14, pp. 35–38). The authors report on an investigation of the efficiency of four types of pneumatic chipping chisels. The types comprised : (*a*) 0·81% carbon steel ; (*b*) steel containing chromium 1·09%, tungsten 2·12% and vanadium 0·22% ; (*c*) silicon-manganese-molybdenum steel ; and (*d*) chromium-molybdenum steel. The loss in weight of the chisels, the weight of chips removed and the effect of increasing the air pressure on the pneumatic tool were studied. In all cases the chisels lost weight at a diminishing rate until near the point of failure. By increasing the air pressure, 50% heavier cuts could be made in 32% less time ; this saving of time would probably reduce chipping costs and would more than repay the additional sharpening, re-dressing and replacement costs incurred.

Wear, and What Can be Done about It. G. T. Williams. (Metal Progress, 1941, vol. 40, July, pp. 63–66). The author describes a number of types of wear such as abrasion caused by dirt, the scoring and galling caused by loose metal particles or metal projections on one surface sliding against another, and the pitting of gear-teeth.

Reports on Special-Duty Cast Irons. II. Austenitic Cast Irons. J. G. Pearce. (Institution of Mechanical Engineers : Foundry Trade Journal, 1941, vol. 65, Aug. 28, pp. 139–142). This is the second of the reports prepared at the instigation of the Research Committee of the Institution of Mechanical Engineers. In it the author gives information on the mechanical properties ; resistance to wear, heat and corrosion ; machinability ; weldability ; expansion ; thermal conductivity ; and electrical properties of the commercially available austenitic cast irons such as " Nomag," " Niresist " and " Nicrosilal."

Reports on Special-Duty Cast Irons. III. Martensitic Cast Irons. J. G. Pearce. (Institution of Mechanical Engineers : Foundry Trade Journal, 1941, vol. 65, Sept. 4, pp. 158, 154). In this third report on the properties of special cast irons the author discusses the manufacture and the mechanical, physical, electrical and machining properties of the martensitic cast irons. Of the martensitic irons specially made to resist wear, two varieties are possible, according to the state of the eutectic filling around the primary grains. In the harder variety this filling is allowed to solidify white, *i.e.*, to form cementite ; in the less hard variety the filling is allowed to solidify grey. The latter may be made martensitic in the as-cast condition, or may be heat-treated to give a similar structure. The greater industrial need has been for the harder variety. The type has various trade names, but is best known as

" Ni-hard," which contains about 4·5% of nickel and 1·5% of chromium.

Microstructure and Machinability. N. E. Woldman (Iron Age, 1941, vol. 147, June 19, pp. 37–40; June 26, pp. 44–49). The author discusses the suitability for different machining operations, such as automatic machining, drilling, boring, reaming, broaching, rough turning, milling and finish turning, of three types of special steel used for making highly stressed gearing for aircraft engines. The steels in question are the chromium-vanadium steel S.A.E. 6150, the nickel-chromium steel S.A.E. 3250 and the nickel-chromium-molybdenum steel S.A.E. 4350.

The Magnetostriction, Young's Modulus and Damping of 68 Permalloy as Dependent on Magnetization and Heat Treatment. H. J. Williams, R. M. Bozorth and H. Christensen. (Physical Review, 1941, vol. 59, June 15, pp. 1005–1012). The authors describe how measurements were made of the changes in certain physical properties of 68 Permalloy that result from different thermal and mechanical treatments, and consider them in relation to the domain theory. The magnetostriction varied with heat treatment from $2·5 \times 10^{-6}$ to 22×10^{-6}. The change in Young's modulus with magnetisation to saturation varied from 0·09% to 10·5%. The damping of mechanical vibrations was also measured as dependent on magnetisation and heat treatment. Young's modulus and the damping constant were determined by measuring the natural frequency of vibration and the width of the resonance curve of a hollow rectangle magnetised parallel to its sides so that the magnetic circuit was complete without air gaps or end effects.

Measurement of Core Loss and A.C. Permeability with the 25-cm. Epstein Frame. S. L. Burgwin. (American Society for Testing Materials, 1941, Preprint No. 41). The author describes the apparatus in use at the Westinghouse Research Laboratories, East Pittsburgh, for making a combined core-loss and magnetic permeability test by the Epstein method on samples of steel strip 28 cm. long with a total weight of about 1 lb. Two procedures for obtaining test data which have proved to be quite satisfactory are described step by step, together with the necessary formulæ for calculating the results.

Magnetic Penetration. T. F. Wall. (Engineer, 1941, vol. 172, Sept. 12, pp. 166–167). According to the classical theory of magnetisation, if a straight steel tube is placed in a long solenoid and magnetised by means of direct current, the magnetic force due to the free poles at or near the ends of the tube should be the same at a point inside the tube as at a point near the surface outside the tube. In order to test this theory the author carried out two groups of tests, using for the first a cold-drawn mild steel tube 4 ft. long, $\frac{3}{8}$-in. inside dia. with a $\frac{3}{16}$-in. wall, and for the second a nest of three steel tubes arranged co-axially, all 4 ft. long, with $\frac{1}{32}$-in. walls and with internal diameters of $\frac{3}{8}$ in., $\frac{9}{16}$ in. and $\frac{3}{4}$ in.

respectively. A system of search coils was used to obtain accurate measurements of the magnetic field strength at points outside and inside the tubes. From the test results of the first group it was observed that when the magnetisation of the tube was small, and when the tube was magnetised to saturation, the force in the bore was practically the same as it would have been had the tube been removed altogether from the solenoid. It may therefore be said that the steel tube was " magnetically porous " for the two conditions—*i.e.*, when completely demagnetised, and when magnetised to saturation in the direction of its axis. The second group of tests showed that for values of the exciting currents greater than about 1·75 amp. the magnetic intensity of the bore of the inner tube was exactly the same as though the nest of tubes had been removed from the solenoid, whilst the magnetic intensity outside the nest was reduced by the presence of the tubes in the solenoid, and this reduction obtained for the whole range of exciting currents used. The concept of " magnetic porosity " provides a reasonable explanation of these effects, and is in accord with the view that magnetisation is initiated at the surface of a ferro-magnetic substance and penetrates from the surface into the body of the material.

Studies on the Magnetization of Single Crystals of Iron and Iron-Nickel Alloys in Very Weak Fields. Y. Simizu. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, May, pp. 175–188). (In Japanese). The author describes the apparatus used and discusses the results obtained when measuring the magnetisation of single crystals of iron and of iron-nickel alloys in weak magnetic fields.

The Classification of Permanent Magnet Materials in Accordance with their Magnetic Properties. W. Zumbusch. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 127–131). The author points out that owing to the lack of clear sub-divisions of the magnetic properties of permanent magnet materials into ranges to meet the requirements of the electrical industry there has been a large and unnecessary increase in the number of such materials produced, with the result that the expensive alloying elements are not used in the most economic manner. The requirements of a standard specification for permanent magnet materials are discussed and a table is presented showing the composition and magnetic properties of 41 German alloys arranged in order of increasing magnetic energy.

New Heat-Resistant Alloys of the Fe-Cr-Al Type with High Electrical Resistance. I. Kornilov. (Stal, 1940, No. 5–6, pp. 59–60). (In Russian). On the basis of the determination of the equilibrium diagram and the use of low-carbon chromium-aluminium hardeners, new heat-resistant alloys of the iron-chromium-aluminium type have been developed which are claimed to be superior to existing alloys of this kind. Unfortunately no compositions are given, but the following properties are claimed : Alloy (1) containing 78–90% of iron, tensile strength 50–60 kg. per sq. mm. ;

elongation 18–25%; working temperature 1000–1100° C.; specific electrical resistance 1·40–1·60 ohms per sq. mm. section per m. length; temperature coefficient of resistance 0·00005. Alloy (2) containing 68–69% of iron, tensile strength 60–65 kg. per sq. mm.; elongation 18–20%; working temperature 1200–1250° C.; specific electrical resistance 1·45–1·70 ohms per sq. mm. per m.; temperature coefficient 0·00004. Alloy (3), containing 50–55% of iron, working temperature 1350–1400° C.; specific electrical resistance 1·70–1·90 ohms per sq. mm. per m.; temperature coefficient 0·00003. A rheostat alloy was also developed; this contains 85–90% of iron, has a working temperature of 600–800° C. and a specific electrical resistance of 1·20–1·40 ohms per sq. mm. per m. Alloys (1) and (2) and the rheostat alloy can be cold- and hot-worked. Alloy (3) can only be hot-worked. The hot-drawing of alloy (3) into wire is now being developed. All these alloys can be gas and arc welded. A 1/1 mixture by weight of CaF_2 and KCl is recommended as a flux for welding.

The Thermal and Electrical Properties of Iron and Steel. J. W. Donaldson. (Journal of the West of Scotland Iron and Steel Institute, 1941, vol. 48, Part V., pp. 59–66). The author surveys the results of investigations carried out in recent years on the thermal conductivity, electrical resistivity, thermal expansion and specific heat of iron and steel.

The One-Hour Stepped Test as a Rapid Method of Determining Creep Strength. H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 533–537). In a previous investigation of creep-testing methods by the present authors '(see Journ. I. and S.I., 1940, No. I., p. 99 A) it was established that a quantitative evaluation of the creep strength of steel specimens could be made from observations of the permanent elongation at the end of one hour's application of each successive load. This is referred to as the one-hour stepped test. In the present paper the authors study the effects of the preheating time, the time during which the load is removed, the number of steps, and the value and duration of the preliminary load on the results obtained by this test, and find them to be very small. As the scatter of the plotted results is small and the time required is short, this test is thought to be a useful and reliable means of maintaining a constant check on the creep properties of steel.

The Creep Strength of Heat-Resisting Steels at 600°, 700° and 800° C. A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 9, pp. 137–148). The authors describe a series of creep tests of several hundred hours' duration at temperatures in the range 600–800° C. on twenty different steels comprising three chromium-molybdenum steels, six chromium-manganese steels, six chromium-nickel steels and five chromium-cobalt steels. The tests were made by the German standard method DVM-A117; this method determines the maxi-

mum stress at which an initial elongation of the material will in course of time cease to increase, but which, if exceeded, will cause a continuous elongation until fracture occurs. The investigation showed, however, that at the above temperatures this method of testing did not give satisfactory values, and that it only provided a means of making rough comparisons of the behaviour of the different steels.

On the Solubility of Nitrogen in the Delta and Liquid Iron. I. Hayashi. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 884–888). (In Japanese). The author determined the solubility of nitrogen in pure molten iron at temperatures of 1400° C. and higher. He found that the solubility decreased abruptly when the $\gamma \to \delta$ transformation point was reached and that the temperature of maximum solubility was that of the melting point.

Here's How Molybdenum-Tungsten High-Speed Steel Can be Used to Replace 18-4-1. J. V. Emmons. (Steel, 1941, vol. 109, July 14, pp. 58–61). The author gives details of the composition and properties of a number of molybdenum-tungsten high-speed steels containing 5·75–9·50% of molybdenum and only 1·00–1·50% of tungsten which have been successfully used in place of the steels containing tungsten 18%, chromium 4% and vanadium 1%.

The Substitution of Nitrogen for Nickel in Austenitic Chromium-Nickel Steels. W. Tofaute and H. Schottky. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 71–76). The authors compared the structures and the mechanical, magnetic and corrosion-resistance properties of a steel containing carbon 0·06% max., chromium 23%, nickel 3–5% and nitrogen up to 0·3% with those of 18/8 stainless steel in order to ascertain whether the deliberate addition of nitrogen could be used as a substitute for some of the nickel. It was found that a high-chromium steel with an austenitic structure could be produced by the introduction of nitrogen, using very little nickel, provided that the carbon was less than 0·1%. Such a steel could be cold-worked and would stand up to long-time annealing. Tests on sheet and bar of these nitrogen-bearing, low-nickel, high-chromium steels produced on an industrial scale proved that the steel had a remarkably high elastic limit, could be easily worked and had good welding and deep-drawing properties. Its resistance to oxidising acids and chloride solutions was equal to or better than that of 18/8 steel. The specimens tested were not susceptible to intercrystalline corrosion.

The Effect of Alloying Additions on Some of the Properties of Heat-Resisting Iron-Aluminium Alloys. H. Cornelius and W. Bungardt. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 539–542). The authors report on their investigation of the structure, forgeability, bending-impact strength, hardness and scale formation of iron-aluminium alloys with 5–10% of aluminium at 1100° C. in air. In particular the effect of separate additions of carbon, manganese, nickel, cobalt, copper, silver, silicon, chromium,

tungsten, molybdenum, vanadium, titanium, boron and niobium + tantalum, were examined. The brittleness of the alloy can be considerably reduced by small additions of titanium and niobium + tantalum without detriment to the other properties, but even in this improved state the alloy is still too brittle to be used as a scale-free forgeable material. The addition of boron also reduces the brittleness, but this element is very detrimental to the scaling resistance.

Ledloy Lead-Bearing Steels. (Engineering, 1941, vol. 152, Sept. 12, p. 205). Some information on the properties of "Ledloy" lead-bearing steel made known by W. B. Wragge in a recent lecture and in a report by the Research Department at Woolwich are given. It is shown that the presence of lead has no harmful effect on the tensile properties of lead-bearing steel specimens cut at right-angles to the rolling direction. The results of some corrosion tests showed that the difference in corrosion resistance between Ledloy steel and ordinary steels is small.

Addition of Bismuth for Producing Free-Machining Stainless Steels. H. Pray, R. S. Peoples and F. W. Fink. (American Society for Testing Materials, 1941, Preprint No. 29). The authors discuss the general metallurgy of the bismuth-bearing alloys and describe laboratory tests on the effect of adding bismuth to corrosion-resistant steels. It is shown that additions of 0·1–0·5% of bismuth markedly increase the machinability without detriment to the corrosion resistance. The laboratory test results are supported by plant and service experience.

Plain and Alloyed Irons Used in Automobiles. H. S. Austin. (Metal Progress, 1941, vol. 39, June, pp. 697–701). The author discusses the composition, structure and properties of a number of cast irons used in the manufacture of automobile cylinder blocks, cylinder liners, exhaust manifolds, brake drums, camshafts and valve tappets.

Comparative Study of the Quality of Thomas Steel and Open-Hearth Furnace Steel. K. Kikuchi and M. Iwafuji. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 865–875). (In Japanese). The authors compare the analyses and mechanical properties of open-hearth and basic-Bessemer steel. Gas analyses showed that there was more nitrogen in the latter, and this had the effect of increasing the tensile strength. The general conclusion was that there was nothing to choose between the two types of steel in the rolled state for structural purposes.

Spark Patterns of the Elements. W. Baukloh. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 543–547). The author studied the ability of thirty-nine elements to form sparks when ground with an alundum wheel. It was established that the spark-forming elements belong mainly to the first sub-groups of the three long periods of the periodic system. No direct relationship was found to exist between either the hardness or the heat of

combustion and the ability to form sparks. A sufficiently high heat of combustion is a necessary condition for spark formation, and the nature of the pattern depends on the combustion process and the constitution of the solid or liquid products of combustion. The occurrence of minute explosions (seen as small stars) is caused by either the formation of gaseous products of combustion or the vaporising of the metal. The process of the formation of spark patterns must be considered to be the result of a complicated heterogeneous decomposition.

Inspection of Steel as to its Composition. H. B. Pulsifer. (Metal Progress, 1941, vol. 40, July, pp. 52–56). The shortage of skilled metal inspectors in the United States has led to a demand for courses of lectures and for a small handbook on inspection. The present article is taken from a handbook on steel inspection which the author was commissioned to prepare for the American Society for Metals. In it the author explains a number of simple and rapid tests (such as hardness and spark tests) for determining the approximate amount of carbon in steel, a test for detecting nickel, sulphur prints and the use of the spectroscope.

Metallurgical Factors in the Selection of Steels. G. T. Williams. (Metal Progress, 1941, vol. 39, June, pp. 721–726). The author discusses the relative importance of composition, grain size and hardenability in the selection of steels for particular purposes.

Manganese in the Steel Industry. (Metallurgia, 1941, vol. 24, July, pp. 82–85). The reasons for the use of manganese in the steel industry are briefly reviewed, and the consumption of manganese, the distribution of the ores and their availability, possible economies and the use of other materials as deoxidising agents or to increase the strength of steel are discussed.

A New Stainless Steel for the Paper Pulp Industry. G. C. Kiefer. (Metal Progress, 1941, vol. 40, July, pp. 59–62, 90). The author discusses the properties of three types of stainless steel and their application for different parts of plant in the paper-pulp industry. The compositions of the three steels are : (1) Chromium 19–22%, nickel 10–12% ; (2) chromium 18–20%, nickel 12–14%, molybdenum 3–4% ; and (3) chromium 25–30%, nickel 3–5%, molybdenum 1–1·5%.

The Fabrication of Carbon–Molybdenum Piping for High-Temperature Service. R. W. Emerson. (American Society for Testing Materials, 1941, Preprint No. 27). The author discusses the effects of hot fabrication, such as upsetting, hot bending, forging and welding, on the physical and metallographic properties of low-carbon, 0·5%-molybdenum steel, and how these effects can be removed by appropriate heat treatment.

1500 Tool Steels. T. W. Lippert. (Iron Age, 1941, vol. 147, May 15, pp. 55–59 ; May 22, pp. 64–68 ; May 29, pp. 51–54 ; June 12, pp. 65–68 ; June 19, pp. 58–60 ; June 26, pp. 52–54 ; vol. 148, July 3, pp. 56–59). A list in alphabetical order is presented of the

trade names of practically all the American tool steels. Brief particulars of the steel in question and the name of the manufacturer or distributor are given after each name.

A Practical Classification of Tool Steels. D. E. Roda. (Iron Age, 1941, vol. 147, June 26, pp. 33–38). The author discusses the characteristics of different tool steels and proposes a scheme of classification for these steels which could be applied in the storerooms of machine shops of motor-car manufacturers.

Wrought Steels (Carbon and Alloy Steels). T.A.C. 1–33. (British Standard Institution, No. 971–1941). War conditions have emphasised the necessity for rationalising steel specifications with the object of making a very substantial reduction in the number of such specifications, and to meet this need the present schedule was prepared by the Technical Advisory Committee of the Aircraft Special and Alloy Steels Committee of the Steel Control of the Ministry of Supply. It covers billets, bars and light forgings up to and including 6-in. ruling section, and is to be regarded as a companion document to British Standard No. 970.

Layout and Equipment of a Modern Steelworks Laboratory. (Sheet Metal Industries, 1941, vol. 15, Oct., pp. 1257–1259, 1264). An illustrated description is given of a modern steelwork's laboratory in South Wales for controlling the quality of all classes of steel sheet and tinplate.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 188 A–191 A)

New Etching Media for Iron and Steel. R. Pusch. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 15–25). The author reviews the literature on etching media and procedures for the etching of plain, low-alloy and high-alloy steels and cast irons, giving a bibliography of ninety references.

X-Ray Stress Determination without a Calibrating Material. H. Möller. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 67–68). The author discusses the advantages and limitations of a modification of the standard X-ray method of determining lattice constants. In the new method (developed by A. Thum, K.-H. Saul and C. Petersen) a cylindrical film with the X-ray beam as its axis is used and no calibrating material is required. It follows that when the film is held flat the interference lines will be straight. A longer slit can therefore be used for the photometric measurement so that the effects of coarse grain of the films and of variations in the blackening curve are lessened.

An X-Ray Investigation of Iron-Nickel-Chromium Alloys. A. J. Bradley and H. J. Goldschmidt. (Iron and Steel Institute, 1941, this Journal, Section I.). X-ray powder photographs of

iron-nickel-chromium alloys were taken in a 9-cm. camera using chromium radiation, the powders being slowly cooled down to room temperature. The positions of the phase boundaries on the constitutional diagram were estimated from the relative amounts of the different constituents present. Four single-phase fields were found, α, body-centred cubic (iron-rich), α', body-centred cubic (chromium-rich), γ, face-centred cubic (nickel-rich), and σ, complex structure (corresponding to the compound FeCr). The two-phase fields are α + γ, α' + γ, α + σ, α' + σ, γ + σ, and the three-phase triangles are α + γ + σ and α' + γ + σ. The results therefore confirm the diagram proposed by Schafmeister and Ergang, but the positions of the boundaries of the phase fields are different, showing that alloys in many parts of the system are extremely susceptible to heat treatment at low temperatures.

The addition of nickel to the iron-chromium alloys greatly increases the range of the σ phase. Whereas in the binary system it is practically confined to the exact composition FeCr, in the ternary system it extends from about 45% to 60% of chromium and up to about 6% of nickel.

The Crystal Structure of Cementite, Fe_3C. H. Lipson and N. J. Petch. (Journal of The Iron and Steel Institute, 1940, No. II., pp. 95 P–103 P). At the end of Section I. of the present volume will be found a corrected version of the table of observed positions and intensities of lines in the X-ray pattern of cementite, taken with Co K_a radiation, which the authors include in their reply to the correspondence on the paper (*loc. cit.*, p. 106 P).

Report of Subcommittee VII. on Microstructure of Cast Iron. (American Society for Testing Materials, Report of Committee A-3 on Iron, 1941, Preprint No. 7, pp. 6–19). In this Report a recommended practice for evaluating the microstructure of graphite in grey cast iron is described. Two series of photomicrographs and drawings covering the complete range of size and type of graphite commonly found in grey irons are given and a description of a standard procedure for evaluating the microstructure of graphite and a suggested method for the metallographic polishing of this iron are also included. An appendix contains a bibliography on the classification of graphite in cast iron.

Persistent Austenite. H. E. Arblaster. (Metals Treatment Society of Victoria : Australasian Engineer, 1941, vol. 41, July 7, pp. 16a–17, 26–32a). The author gives a comprehensive account of the factors affecting the α → γ and the γ → α transformations in iron and steel with particular reference to those which promote the retention of austenite at room temperature. Pure iron and the iron-carbon alloys are considered first, and the effect of other alloying elements is dealt with next, the latter being divided into two groups, the first comprising nickel, manganese, nitrogen and cobalt which widen the stability range of γ-iron ; the second includes chromium, silicon, phosphorus, tungsten, molybdenum, vanadium

and aluminium which increase the stability range of α-iron and
δ-iron.

**Contributions to the Data on Theoretical Metallurgy. IX. The
Entropies of Inorganic Substances. Revision of Data and Methods
of Calculation.** K. K. Kelley. (United States Bureau of Mines,
1941, Bulletin 434). In 1932 the Bureau of Mines issued a bulletin
in which were listed the entropy values then available for about
150 elements and inorganic compounds. This was revised in 1936.
In the present bulletin the information in the first one is revised,
the entropy data published since 1935 are added and an explanation
is given of the methods employed in calculating entropies. A
bibliography with 419 references is appended.

Some Remarks on the Transformation of Austenite. K. Iwasé
and S. Takeuti. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, Apr.,
pp. 131–136). (In Japanese). The authors discuss the trans-
formation of austenite in carbon steels with particular reference
to : (a) The reason why there is more retained austenite in an oil-
quenched specimen than in a water-quenched one ; (b) the differ-
ence between primary and secondary troostite ; and (c) the cause
of the irreversibility of the A_3 transformation of iron-nickel alloys.

CORROSION OF IRON AND STEEL

Practical Aspects of Contact Corrosion in Metals. H. Silman
and A. Freeman. (Sheet Metal Industries, 1941, vol. 15, Sept.,
pp. 1129–1134). The authors discuss the mechanism of contact
corrosion in respect of iron and steel and a number of other metals
and alloys. They explain the electro-chemical effects and make
recommendations as to the metallic couples which may be con-
sidered relatively safe from corrosion. The requirements of inhibi-
tive paints and pastes are also dealt with.

Notes on Current Corrosion Problems. T. M. Riddick. (Journal
of the American Water Works Association, 1941, vol. 33, May,
pp. 903–907). The author discusses theory and practice regarding
the corrosive action of different waters. In one investigation he
classified samples of fifty different waters into three groups, namely,
extremely corrosive, moderately corrosive and non-corrosive, with-
out regard to their chemical analysis and pH value. A critical
examination of all the known data showed that this classification
did not conform with the theory of pH control, that of the effect
of carbon dioxide, or that of the supersaturation of calcium car-
bonate ; it did bring out the relationship between alkalinity and
hardness and demonstrated that the lower the magnesium sulphate
content, the less corrosive was the water.

Causes of Corrosion Currents. R. B. Mears and R. H. Brown. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Aug., pp. 1001–1010). The authors discuss how the following factors affect the difference in potential between different parts of a metal surface when it is immersed in water or a solution which corrodes the metal : (1) The orientation and size of the grains ; (2) the grain boundary material ; (3) non-uniform heat treatment ; (4) surface roughness ; (5) different states of stress ; (6) conditions of exposure before immersion ; (7) non-uniform concentration of the corroding medium ; (8) differences in aeration, heating, illumination and agitation ; (9) contact with other metals ; and (10) externally applied potentials.

Cathodic Protection on Domestic Distribution System at Treasure Island. C. H. Lee. (Journal of the American Water Works Association, 1940, vol. 32, Feb., pp. 305–338). The author gives an account of the difficulties met with because of the corrosion of the steel water pipes which were put down to supply the Golden Gate International Exposition at Treasure Island, San Francisco, and how these were dealt with by the application of cathodic corrosion control. Forty miles of thin-walled steel tube were laid and leaks were reported within five months. The leaks were found to be due to excessive pitting caused by soil corrosion intensified by galvanic currents induced by extreme and localised differences in the moisture in the soil and in the salt content of the dredged material at the exhibition site in which the pipes were buried. The soil conditions are described in detail. The principle of cathodic protection and its application to steel tanks have been described previously (*see* Journ. I. and S.I., 1940, No. II., p. 231 A). In the present paper full particulars are given of the design of the protection installations at Treasure Island, the tests applied, the current consumption, the cost and the record of leaks ; this record showed that the number of leaks was reduced from fifteen per week to zero.

Corrosion and Cathodic Protection. G. H. Montillon. (Journal of the American Water Works Association, 1941, vol. 33, Feb., pp. 302–308). The author reviews the literature on efforts to prevent the corrosion of metals with particular reference to the cathodic protection method.

An Equation Representing the Rate of Development of Rust on Galvanized Iron Sheets as Estimated by the A.S.T.M. Test. J. B. Austin. (American Society for Testing Materials, 1941, Preprint No. 37). The author derives an equation which represents, within the accuracy of observation, the change in the rate of rusting of galvanised iron sheets with change in atmosphere and with change in weight of the zinc coating.

Pitting and its Effect on the Fatigue Limit of Steels Corroded under Various Conditions. D. J. McAdam, jun., and G. W. Geil. (American Society for Testing Materials, 1941, Preprint No. 33).

The authors examined the form, size and distribution of the pits in the surface of carbon and alloy steels caused by corrosion in well water, a river water, distilled water, soft water and a salt-water spray. The results of this study are correlated diagrams showing the lowering of the fatigue limit by the corrosion. The pits in the steels tested were at first approximately hemispherical, they then became saucer-like and spread irregularly along the surface. The change was more rapid with carbon steels than with alloy steels. The carbon steels, especially when subjected to salt spray, tended to form sharp, root-like extensions of the corrosion from the bottom of the pits further into the metal. The application of fatigue stresses accelerated the corrosion, and when the combined influence of the stress, the frequency and the corrosion time was sufficiently great a transverse extension of the pits was caused with the formation of crevices or fissures. When this combined influence was not so great, the effect was to increase the size, but not the shape, of the pits.

Corrosion of 18/8 Stainless Steel in Sodium Chloride Solutions. H. H. Uhlig and M. C. Morrill. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, July, pp. 875–880). The authors report on an investigation of factors influencing the corrosion of 18/8 stainless steel in sodium-chloride solutions. The nature of the corrosion and the loss in weight after 24 hr. immersion were observed. It was noted that the corrosion increased sharply with temperature, a maximum being reached at about 90° C. in 4% and 10% sodium-chloride solutions, and at above 90° C. for 1% solutions. At the boiling point the corrosion decreased nearly to zero. In a 4% solution at 90° C. the logarithm of the loss in weight was a linear function of the pH value in the pH 12 to 8 range. The least corrosion occurred at 90° C. when the solution had a pH value of 12.

The Corrosion Resistance of Free-Machining Stainless Steel. S. P. Watkins. (Metal Progress, 1941, vol. 39, June, pp. 710–714). The author presents the results of several series of accelerated corrosion tests on specimens of 12%-chromium, 17%-chromium and 18/8 stainless steels, some of which contained sulphur or selenium to impart free-machining properties. In boiling 65% nitric acid a high sulphur or selenium content materially reduces the corrosion resistance of the steel, but the resistance can be greatly improved by the addition of 0·35–0·50% of molybdenum. Hydrochloric acid strongly attacks stainless steels, but after an initial period the rate of attack is reduced except in the case of the 17%-chromium free-machining quality. The addition of sulphur reduces the resistance of the straight chromium grades to this acid, but has little effect on the 18/8 steel. Selenium tends to reduce the resistance more than sulphur, but the difference is not marked. With stronger solutions and at moderately high temperatures, the attack by hydrochloric acid is greatly accelerated and the difference between

the ordinary and free-machining qualities becomes more marked. The stainless steels, in particular the straight chromium grades, are not regarded as satisfactory for applications in contact with sulphuric acid solutions; the addition of about 3% of molybdenum to the 18/8 grades substantially increases its resistance to this acid. The passivity range is also greatly extended if an oxidising chemical such as nitric acid, copper sulphate or ferric sulphate, is present in the solution in the correct proportions. In acetic acid all grades of stainless steel offer good corrosion resistance, and in 20% acetic acid the free-machining qualities are only very slightly less resistant than the standard qualities. In salt-spray tests the free-machining grades rust to a greater extent than the corresponding regular grade, especially in the case of the straight chromium alloys. After exposure for 125 hr. in running tap water all specimens showed no sign of corrosion. As to oxidation resistance, all specimens had a good resistance up to moderately high temperatures, but at 2050° F. the free-machining qualities had a much greater tendency to form scale than the ordinary qualities.

Corrosion Resistance of Cadmium and Zinc Electrodeposits under Marine Conditions. A. Mankowich. (Monthly Review of the American Electroplaters' Society, 1940, vol. 27, Nov., pp. 833–838). The author describes an investigation of the relative merits of zinc and of cadmium coatings on steel sheet in resisting the attack of 3% sodium-chloride solution. The surfaces of the specimens were examined and loss-in-weight determinations were made after immersion in the solution for various periods. The general conclusions reached were : (1) Cadmium deposits on steel were superior to zinc under conditions of severe exposure ; the change-in-weight data indicated that zinc deposits on steel were subject to excessive anodic corrosion throughout the life of the coating. (2) Cadmium deposits, after suffering approximately the same loss in weight for a short time (160 hr. continuous immersion in 3% NaCl) began to gain weight because of the formation of a film which resists attack. (3) Under mild conditions of marine exposure, and without regard to the unsightly appearance of zinc-coated steel under marine conditions, zinc and cadmium were equally effective in protecting the steel. (4) In the investigation described it was found that cadmium plating 0·00013 in. thick was superior to zinc plating 0·0010 in. thick in its corrosion resistance.

The Bacterial Corrosion of Iron and Steel. T. D. Beckwith. (Journal of the American Water Works Association, 1941, vol. 33, Jan., pp. 147–164). The author considers the corrosion of iron by bacteria. This form of corrosion is generally thought of as a process of reduction, but it is shown that there is an additional mechanism of oxidation whereby iron may be corroded by the physiologic activities of certain types of bacteria. Methods of detecting the organism *Microspira* are described, and some experiments to test the effect of cathodic protection on the action of this

organism on iron showed that it did not interfere with the corrosive influence of *Microspira*.

The Prevention of Corrosion in Steel Chimneys.   A. V. Staniforth. (Engineering, 1941, vol. 152, Sept. 12, pp. 204–205).   The author describes a system of lining steel chimneys with asbestos-cement sheets and sealing the joints with a compound held in place by cast-iron cover bars fixed by cast-iron junction blocks secured to the stack by steel studs.   This method has proved to be successful in preventing the corrosion of the inside of steel chimneys by moisture and sulphurous gases.

Intergranular Changes in an Iron Alloy.   E. Wood and S. T. Harrison. (Nature, 1941, vol. 148, Sept. 6, pp. 286–287).   The authors describe an example of intercrystalline breakdown of high-tensile steel caused by the presence of mercury.   At the works in question oil-hardened nickel-chromium steel dowel pins were pressed into holes in air-hardened steel (carbon 0·28–0·32%, nickel 3·75–4·5%, chromium 1–1·5%) and a series of failures were experienced.   In every case the fracture had two easily distinguishable zones—an initial zone exhibiting what appeared to be brittle fracture and a secondary zone of well-marked fatigue type spreading from this ; the initial zone invariably showed break-up at the edge of the fracture which was connected with intercrystalline boundaries.   The heat treatment and all the workshop processes of manufacture were carefully explored to ascertain the cause, and it was eventually discovered that one operator sometimes used a mercury ointment as an aid to fitting the dowels.   Special specimens were prepared with and without amalgam coatings and were subjected to tensile and fatigue tests ; these definitely established that the mercury was the cause of the failures.

Intergranular Corrosion in Austenitic Stainless Steels.   J. H. G. Monypenny. (Metallurgia, 1941, vol. 24, July, pp. 78–81 ; Aug., pp. 105–109).   The author gives briefly the generally accepted theory of the cause of intergranular corrosion of austenitic stainless steels and describes in detail many of the tests which have been developed to determine the susceptibility of different steels to this form of corrosion under various industrial conditions, with special reference to the temperature range of heat treatment which renders the steels most sensitive.

The Influence of the Attacking Medium on the Intercrystalline Corrosion of Unalloyed Steel.   G. Berndt. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 59–66).   The author reports on an investigation of the factors affecting the intercrystalline corrosion of steel.   By examining bent specimens immersed in aqueous salt solutions, acids and alkalies the following theory was developed.   Steel immersed in an attacking solution becomes covered with a protective film of hydrated iron oxides.   It is obvious that with non-alkali-resisting steels reactions may subsequently occur between the film and the grain-boundary material,

thus causing the adherence of the film at such places to be considerably reduced. The precipitation of the hydrated iron oxides is associated with a corresponding adsorption of large quantities of salts; there is thus a change in the salt concentration within the liquid/iron-oxide-film system in that the salt concentration in the film is greater than that of the original solution. A state of osmotic pressure difference is thus brought about. As molecules of water can penetrate the oxide film and salt molecules cannot, osmotic pressure builds up below the film, particularly where the adherence is poor, *i.e.*, at the grain boundaries. This pressure rises until either the salt concentration is equalised, or the protective film breaks down at one of these places. The breakdown of the film is indicated by a change in the potential towards the negative. The combined effect of the previous plastic and elastic deformation and that of the osmotic pressure causes cracks along the grain boundaries.

It was observed that highly polished specimens of cold-worked steel were much less sensitive to intercrystalline corrosion than planed but unpolished specimens. It is possible, by measurements of potential, to determine whether a given steel would be subject to intercrystalline corrosion in a given solution.

The Conditions of Loading in Different Methods of Testing the Resistance of Steel to Intercrystalline Corrosion. R. Mailänder. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 117–126). The author reviews a number of methods of testing the resistance of steel to intercrystalline corrosion. The methods of testing are divided into two main classes: those in which a constant load is maintained, and those in which the deformation of the specimen remains constant. In both cases the stresses in the specimen change during the period of immersion in the alkaline solution. The most reliable results are obtained from the constant-load tests. Many methods of testing are described and the author considers that, of the constant-load tests, only the cantilever method and that of Herzog and Portevin give really accurate results. The advantages and limitations of the Jones test are discussed.

The Acid Resistance of Finished Enamelware. (Foundry Trade Journal, 1941, vol. 65, July 3, pp. 9–10, 12; Aug. 7, pp. 96–98, 93; Sept. 4, pp. 160–162). A detailed description is given of a method of testing the resistance of finished enamelware to the attack of acids and the results for a number of commercial enamels tested by this method, which is recommended by the Chemical Resistance Test Sub-Committee appointed by the Institute of Vitreous Enamellers in collaboration with the British Cast Iron Research Association. In this first method a disc of filter paper and a second disc of thicker absorbent paper are placed together on the enamelled surface with the latter on top. The acid solution is then dropped on the paper until both discs are saturated. After 15 min. the solution is washed off and the surface is dried and examined.

Using the following solutions, four grades of resistance, *A*, *B*, *C*, and *D*, can be distinguished : (1) 15% hydrochloric acid ; (2) 10% citric acid ; and (3) 2% acetic acid. If the surface is unaffected by all three solutions the enamel is grade *A* ; if affected by (1) but not by (2) or (3), it is grade *B* ; if affected by (1) and (2) but not by (3), it is grade *C* ; if affected by all three solutions, it is grade *D*.

ANALYSIS

Absolute Colorimetry in the Metal Industry. J. E. R. Winkler. (Schweizer Archiv, 1940, vol. 6, July, pp. 194–200). The author explains the principles of the absolute colorimetric method of determining the elements present in alloys, and points out the advantages in simplicity and accuracy of this method compared with the comparison method. In the absolute process a solution of the dissolved sample is put in a vessel having two parallel colourless transparent panels and this is put in the spectro-photometer. This instrument is constructed so that two parts of the field of the eye-piece are illuminated by light of known wave-length and of known spectral purity. The light illuminating one part passes through the solution and therefore loses intensity. The other beam passes through an intensity adjustment device with which its intensity is reduced until it matches that of the first beam ; the amount of the reduction is measured and the scale is calibrated on the basis of the Lambert-Beer law relating the concentration of the solution to the amount of light absorbed by it. In the second part of the paper the preparation of the solution and brief particulars of the procedure for making determinations of the principal elements found in steel and in non-ferrous metals are given with numerous references to the literature.

The Determination of Silicon, Phosphorus and Manganese in Acid-resisting High-Silicon Irons. J. B. Cotton. (Analyst, 1941, vol. 66, July, pp. 286–288). The author describes two methods for the determination of silicon in high-silicon irons. In the first method the sample is fused with sodium peroxide, the melt extracted with dilute hydrochloric acid, the solution obtained evaporated to dryness and the residue treated with 60% perchloric acid. After cooling, water is added and the silica filtered off, washed with 40% hydrochloric acid and ignited. The results obtained are stated to be excellent. The method is lengthy, however, and a further disadvantage is that the solution from the silica filtration contains

considerable amounts of sodium salts and perchloric acid, which prevents its use for the subsequent determination of manganese and phosphorus. In the second method a 0·5-g. sample is dissolved in 10 ml. of a stock solution of hydrobromic acid (" Analar " 46–48%) containing bromine. (Most favourable ratio, 1 ml. of bromine per 10 ml. of hydrobromic acid). After removal of excess bromine and hydrobromic acid by heating for about 15 min., 150 ml. of hot water are added and the clear liquid is decanted. The residue is then treated for 2 min. with 5 c.c. of concentrated nitric acid, diluted to 50 ml., filtered, and the silica determined in the usual way. The results obtained are in good agreement with those of the first method. The second method was checked by applying it to the analysis of the cast iron standard sample, containing 2·22 ± 0·06% of silicon, which is issued jointly by the National Physical Laboratory and The Iron and Steel Institute, and 2·21% and 2·22% of silicon were found. In conclusion some details are given regarding the determination of phosphorus and manganese after dissolution of the sample in the above hydrobromic-acid/bromine stock solution.

A Rapid Method for the Determination of Molybdenum in Molybdenite and Ferromolybdenum. K. Kuroda. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 893–894). (In Japanese). The author gives procedures for making accurate determinations of molybdenum in molybdenite and in ferro-molybdenum.

The Potentiometric Determination of Nickel and Copper in Steel. R. Weihrich. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 55–58). The author describes a rapid method for determining nickel and copper in steel which is based on the direct potentiometric titration with potassium-cyanide solution using silver iodide for the end-point electrode and silver for the indicator electrode. No potassium iodide is required for this method.

Determination of Nitrogen in Iron and Steel by the Kjeldahl Method. T. Somiya and Y. Nakamura. (Tetsu to Hagane, 1940, vol. 26, Dec. 26, pp. 888–892). (In Japanese).

Apparatus for the Determination of Hydrogen in Iron and Steel by the Vacuum Heating Method. II. Gas Collecting Apparatus. T. Somiya. (Tetsu to Hagane, 1941, vol. 27, May, pp. 293–301). (In Japanese). A modified Orsat gas-analysis apparatus for determining the hydrogen in steel was described in Part I. (*See* p. 144 A). In Part II. the furnace for heating the specimen and the equipment for pumping and collecting the gas are described.

Apparatus for the Determination of Hydrogen in Iron and Steel by the Vacuum Heating Method. III. Procedure and Results of Analysis. T. Somiya, Y. Nakamura and S. Shiraishi. (Tetsu to Hagane, 1941, vol. 27, May, pp. 301–305). (In Japanese). The procedure for making hydrogen determinations with the vacuum-fusion apparatus previously described is given and some of the results obtained are discussed.

Studies on the Measurement of Water Vapor in Gases. F. C. Todd and A. W. Gauger. (American Society for Testing Materials, 1941, Preprint No. 95). The authors describe two methods for determining the absolute moisture content of fuel gases. The methods are applicable to both manufactured and natural gas with the impurities normally found in them. One is a laboratory method in which the absorption by water vapour of radiation of about 18,700 Å. wave-length is employed. The second is a colorimetric method for field use.

BOOK NOTICE

(Continued from p. 147 A)

SANDERS, T. H. "*Springs : A Miscellany.*" (In two vols.). Volume I. Including Chapters I. to XIII. 8vo. pp. xv + 457. Illustrated. London (1940) : The Locomotive Publishing Co., Ltd. (Price 50s. two vols.)

This is probably the most useful book about springs that has yet been written and, in view of its contents, the title is very well chosen. Besides being extremely useful from a technical point of view, it is most interesting to read. The first chapter, which deals with the historical side of springs and covers such articles as catapults, cross bows, &c., is particularly fascinating and, at the same time, useful. The most disappointing chapters (Chapters II. and X.) are the two dealing with spring calculations. Although the author has only utilised elementary conceptions of the behaviour of springs, both chapters are difficult to follow and useful formulæ are somewhat hidden away in the text. Chapters IV. to IX. inclusive will probably be the most read chapters of the whole book, as, besides appealing to spring manufacturers and designers, they will have a wide appeal to engineers who are in any way associated with machines or apparatus utilising springs. In other words, they will be of interest to practically every engineer.

Chapters IV., V., VII., VIII. and IX. deal in considerable detail with volute and conical springs, torsion bars, washer springs, friction springs and rubber springs.

Chapter VI. is devoted to the manufacture of coiled springs, whilst Chapters XI., XII. and XIII. are devoted to the consideration of the testing of springs, spring scragging machines, spring-load testing machines and the like.

As is usual in the case of the first volume of a two-volume publication, there is no index. This is the usual practice, but it is to be hoped that ultimately a publisher will break away from the general rule and provide the first volume with its own individual index and the last volume with an index to both volumes.

J. FERDINAND KAYSER.

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SUBJECT INDEX.

[References to the papers read before the Institute are indicated by the word *Paper* following the page number. The letter *P.* denotes a reference in Section I. of the Journal which contains the reports of the proceedings of meetings, the papers read, and the discussions thereon. The letter *A.* denotes a reference to the section dealing with abstracts.

Indexing of Alloy Steels and Other Alloys. In the indexing of alloy steels, carbon and iron are ignored and the alloying elements contained in the steel are arranged in alphabetical order ; for example, all references to nickel-chromium-molybdenum steel will be found under the heading chromium-molybdenum-nickel steel. In the indexing of other alloys, carbon and iron, when present, are included in the title; iron, when present, is always mentioned first and the other elements follow in alphabetical order, carbon being in all cases mentioned last. Examples : " Iron-silicon-carbon alloys " and " iron-chromium-nickel-carbon alloys."]

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